Defense Nuclear Agency
Alexandria, VA 22310-3398

DNA-TR-94-145

Development of a Standardized Granular Target for Use With the DNA/WES Ground Motion Test Facility

Howard G. White
USAE Waterways Experiment Station
Structures Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

April 1995

Technical Report

CONTRACT No. DNA MIPR 93-567

DISTRIBUTION LIST UPDATE

This mailer is provided to enable DNA to maintain current distribution lists for reports. (We would appreciate your providing the requested information.)

- ☐ Add the individual listed to your distribution list.
- ☐ Delete the cited organization/individual.
- ☐ Change of address.

> **NOTE:**
> **Please return the mailing label from the document so that any additions, changes, corrections or deletions can be made easily. For distribution cancellation or more information call DNA/IMAS (703) 325-1036.**

NAME: ____________________

ORGANIZATION: ____________________

OLD ADDRESS	CURRENT ADDRESS
____________________	____________________
____________________	____________________
____________________	____________________

TELEPHONE NUMBER: (   ) ____________________

DNA PUBLICATION NUMBER/TITLE	CHANGES/DELETIONS/ADDITIONS, etc.) *(Attach Sheet if more Space is Required)*
____________________	____________________
____________________	____________________
____________________	____________________

DNA OR OTHER GOVERNMENT CONTRACT NUMBER: ____________________

CERTIFICATION OF NEED-TO-KNOW BY GOVERNMENT SPONSOR (if other than DNA):

SPONSORING ORGANIZATION: ____________________

CONTRACTING OFFICER OR REPRESENTATIVE: ____________________

SIGNATURE: ____________________

CUT HERE AND RETURN

DEFENSE NUCLEAR AGENCY
ATTN: IMAS
6801 TELEGRAPH ROAD
ALEXANDRIA, VA 22310-3398

DEFENSE NUCLEAR AGENCY
ATTN: IMAS
6801 TELEGRAPH ROAD
ALEXANDRIA, VA 22310-3398

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
950401

3. REPORT TYPE AND DATES COVERED
Technical 930113 - 930930

4. TITLE AND SUBTITLE
Development of a Standardized Granular Target for Use With the DNA/WES Ground Motion Test Facility

5. FUNDING NUMBERS
C - DNA MIPR 93-567

6. AUTHOR(S)
Howard G. White

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
USAE Waterways Experiment Station
Structures Laboratory
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Defense Nuclear Agency
6801 Telegraph Road
Alexandria, VA 22310-3398
TDTR/Flohr

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DNA-TR-94-145

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The DNA/WES Ground Motion Test Facility is a vertical gas gun with a 1.22-m diameter projectile. This report describes the selection of a material for use as a standardized granular target. A description of target construction and testing procedures is presented. Stress and velocity time-histories from three identical tests (i.e., identical targets and projectile velocities) are presented. Analyses of the data includes determination of the propagation velocity of the loading and relief waves in a test article.

The results from identical tests indicate that repeatable ground shock environments were generated on each test. The material used as the target medium, the procedures employed in target construction, and the ability of the gun to deliver the projectile at the same velocity combine to produce known and repeatable stress and motion fields in a target. The predictability and repeatability with which these environments can be generated make the facility a unique tool for conducting instrumentation studies.

14. SUBJECT TERMS
Gas Gun
Ground Shock
Ground Motion
Projectile Impact
Instrument Calibration

15. NUMBER OF PAGES
78

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

CLASSIFIED BY:

N/A since Unclassified.

DECLASSIFY ON:

N/A since Unclassified.

PREFACE

The work described in this report was sponsored by the Headquarters, Defense Nuclear Agency (HQDNA) under MIPR 93-567, Work Unit 00001. Mr. Mark Flohr, Test Directorate, Test Requirements, DNA, was the DNA Project Manager.

This study was conducted by the Geomechanics and Explosion Effects Division (GEED), Structures Laboratory (SL), U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. This effort was under the overall direction of Dr. H. G. White. Technical assistance was provided by Dr. C. R. Welch, EED. Field work was coordinated by Messrs. J. T. Byrne and G. R. Jolly, IIT Research Institute. They were assisted by Mr. C. C. Dorrell, EED, and Mr. F. Williams, a contract student with the EED. Laboratory calibration support and field instrumentation support was provided by Mr. C. N. Thompson of the WES Instrumentation Services Division (ISD). Mr. B. C. Barker, ISD, provided field instrumentation supervision and coordination. Dr. White and Mr. Byrne conducted data analyses.

During this investigation, Dr. J. P. Balsara was Chief, GEED, and Mr. B. Mather was Director, SL.

At the time of preparation of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degree	0.01745329	radians
feet	0.3048	meters

TABLE OF CONTENTS

FIGURES

FIGURES (Continued)

SECTION 1

INTRODUCTION

1.1 BACKGROUND.

The Defense Nuclear Agency funded the Geomechanics and Explosion Effects Division (GEED) of the USAE Waterways Experiment Station (WES) to develop a large-bore vertical gas gun (Welch, 1983; Joachim, 1985; Ohrt, 1988a, 1988b; White, 1988, 1990a, 1990b, 1990c; and White, et al., 1994). The primary purpose of the gas gun is to simulate ground shock environments in a manner suitable for testing ground shock measurement devices. In order to make optimum use of the gun to validate or test ground motion sensors, the target (i.e., the specimen in which the ground shock instruments are tested) must have predictable and repeatable properties. The development and implementation of procedures to prepare well-controlled targets is vital in achieving the stated purpose of the gun.

Twenty-five tests were conducted with the gas gun. The primary objectives for the first 22 tests were to develop safe procedures for testing and to determine the operating characteristics of the gun (e.g., determine projectile velocity, far-field ground motion and nuisance noise levels as a function of vessel pressure). The performance aspects of testing with the gas gun were reported by White (1993a). Twelve of the first 22 tests also included sand targets containing ground shock instrumentation. Analyses of the results of the initial tests with regard to the ground shock generated in the target were reported by White and Byrne (1994). Variances in the environment measured on these tests identified the need for developing a standardized granular target.

1.2 DESCRIPTION OF DNA/WES GROUND MOTION TEST FACILITY.

A cutway view of the DNA/WES Ground Motion Test Facility (also know as the WES 4-ft Diameter Vertical Gas Gun) is given in Figure 1-1. The gun is approximately 6.3 m long, 2.6 m in

diameter (at its widest point), and has a mass of 15,000 kg. It consists of a large annular pressure vessel surrounding a vertical barrel. A series of orifices is machined in a 0.7-m-long section of the barrel located about one-third of the barrel height below the top. This allows the compressed air from the vessel to expand into the barrel. When the gun is in the cocked position, a projectile containing o-ring seals at the top and bottom straddles the orifices. These seals prevent the compressed air from being released into the barrel. The projectile is held in place by a quick-release trigger mechanism. A water reaction mass fills the top portion of the barrel above the trigger mechanism. The bottom of the barrel may be sealed with a diaphragm to allow a partial vacuum to be created in the barrel section below the projectile.

To fire the gun, the projectile is first released by the trigger mechanism. The weight of the projectile causes it to move downward. As the top o-ring clears the orifices, the compressed air expands into the barrel. The incoming air simultaneously drives the projectile downward and the water reaction mass upward. Water was chosen as the material for the reaction mass for convenience and to eliminate any hazards as the mass falls back to the earth after a test. The gun has a maximum operating pressure of 2070 kPa, which produces a projectile velocity of about 70 m/sec.

The projectile design is shown schematically in Figure 1-2. The projectile consists of a 0.86-m long by 1.22-m diameter carriage. Suspended beneath the carriage is a 1.19-m diameter impact plate, which for the tests reported here was a 50-mm thick steel plate. Rigid polyurethane foam is sandwiched between the impact plate and the carriage to reduce the impact-induced loads on the carriage and prevent damage. The thickness of the foam used in the projectile for the tests described in this report was 175 mm. The total mass of the projectile for these tests was 1,480 kg.

Photographs of the gas gun at its permanent location at WES are presented in Figures 1-3 and 1-4. The gun is surrounded by an earthen berm, except for an access road (not visible in the photographs). Directly adjacent to the gun are three buildings. The cinder block building is used as a work room and storage room. The small portable building behind the cinder block building (seen in Figure 1-4) is used as a storage facility. The shed behind the gun in Figure 1-4 houses several components of the fill system used in operating the gun.

Also seen in Figure 1-3 are instrument cables running along the tops of poles. These cables terminate in the Control Trailer, barely visible behind the trees in the top left corner of Figure 1-3. The Control Trailer is the control center for conducting a test. Instrument recorders and the control panel used for operating the fill system are located in the trailer. The Control Trailer is located at the closest range (53 m) at which a test may be viewed by spectators. Various parts used in conducting a test are also seen in the two photographs, e.g., the three components of the projectile (carriage, energy-absorbing foam, and impact plate), the tripod for loading the projectile into the gun, and the canvas covered frame used for moving the projectile and targets into the trench beneath the gun. Additional information on the 4-ft gas gun may be found in White et al. (1991); White (1993a, 1994a, and 1994b); White and Byrne (1994); and White and Welch (1994).

1.3 OBJECTIVES.

The objective of this study was to develop a standardized granular target for use with the gas gun. This consisted of:

(1) selecting a single material for use as the medium;

(2) developing procedures for placing the material;

(3) selecting methods to monitor the quality of the material placement;

(4) developing procedures for accurately placing diagnostic and active instrumentation in the target.

The ability to construct identical targets is a portion of the problem in conducting gage validation tests. Developing the same environment in the target from test to test depends on the ability of the gas gun to deliver the projectile at a known and repeatable velocity. In the current study, three identical tests (Tests 23, 24, and 25) were conducted to evaluate the variation in the environment generated in a target.

1.4 SCOPE.

This report describes the selection of the granular material used for standardized targets. Also described are target construction procedures and testing methods used for conducting three identical gas gun tests. Results and conclusions from the three tests are presented.

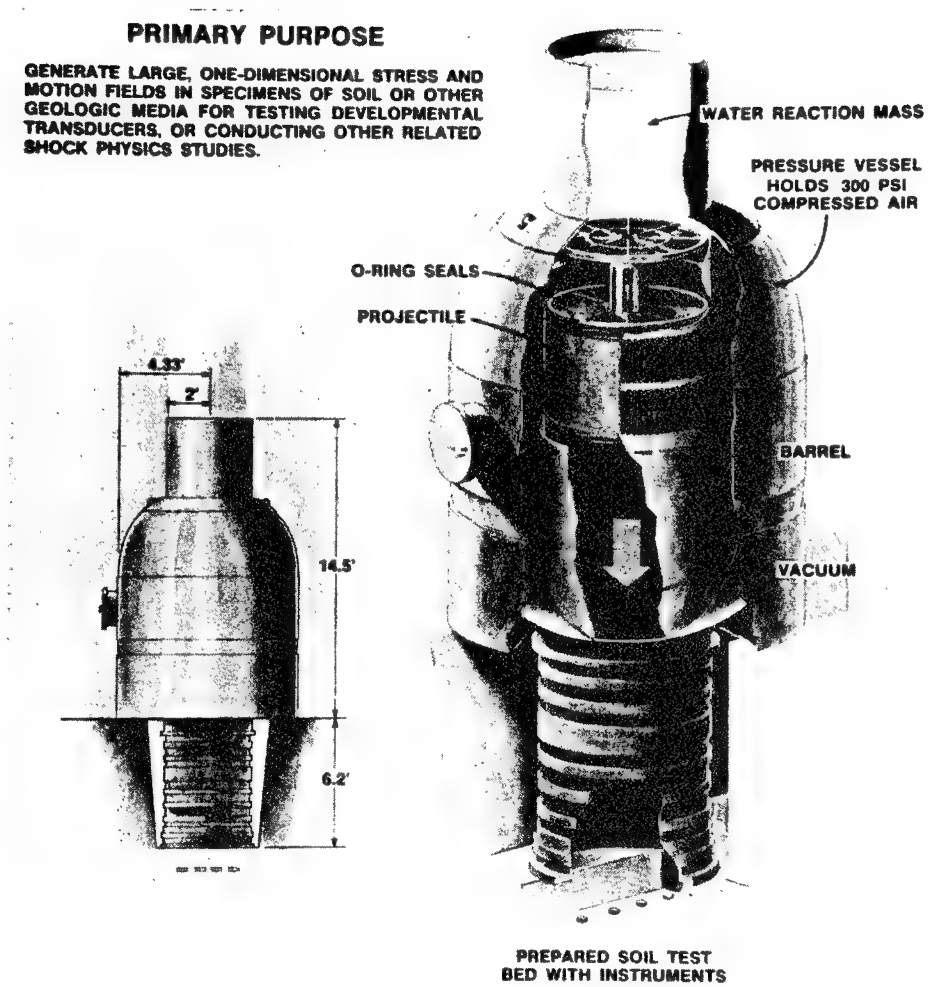


Figure 1-1. Cutway view of the 4-ft diameter vertical gas gun.

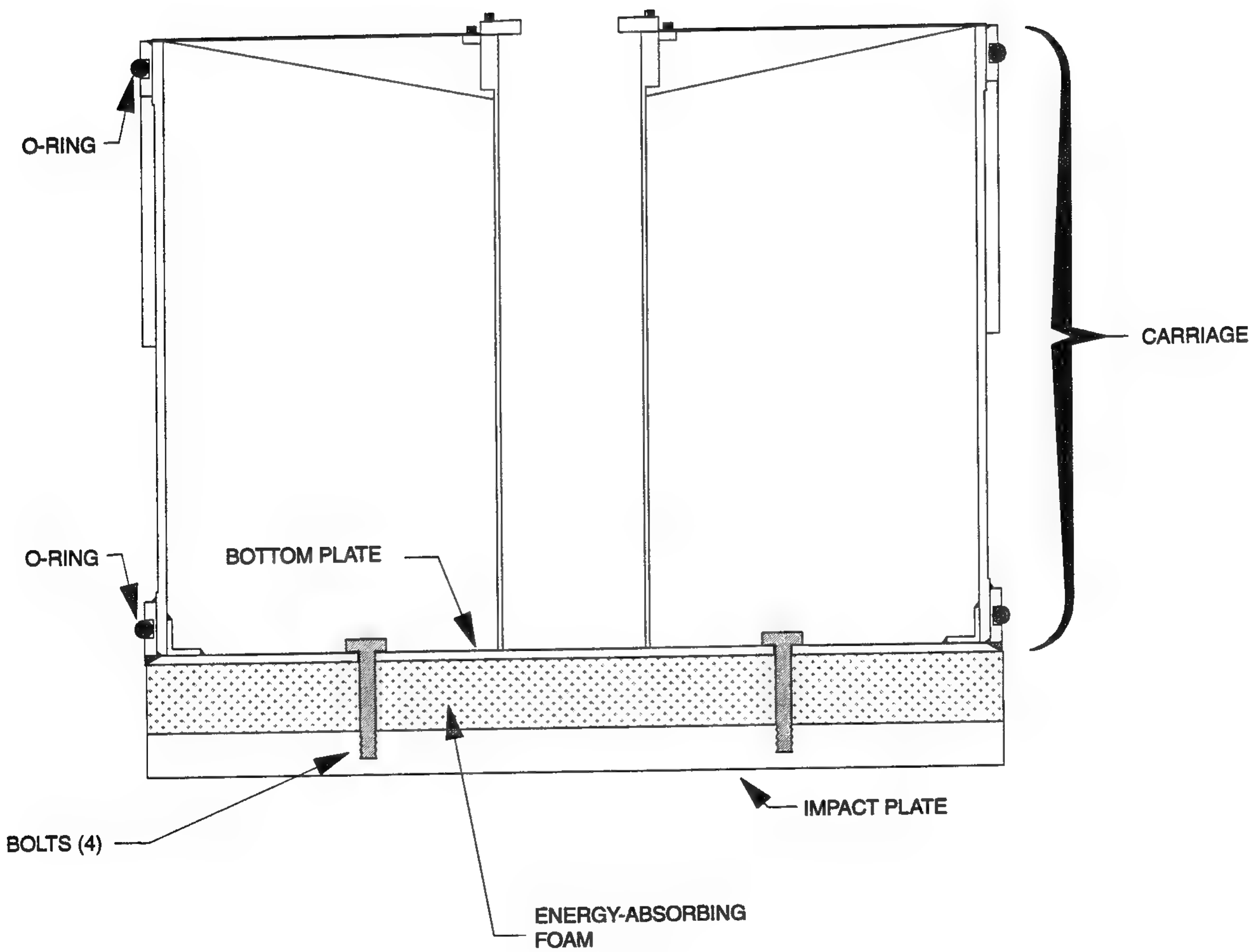


Figure 1-2. Schematic of the projectile used with the 4-ft diameter gas gun.

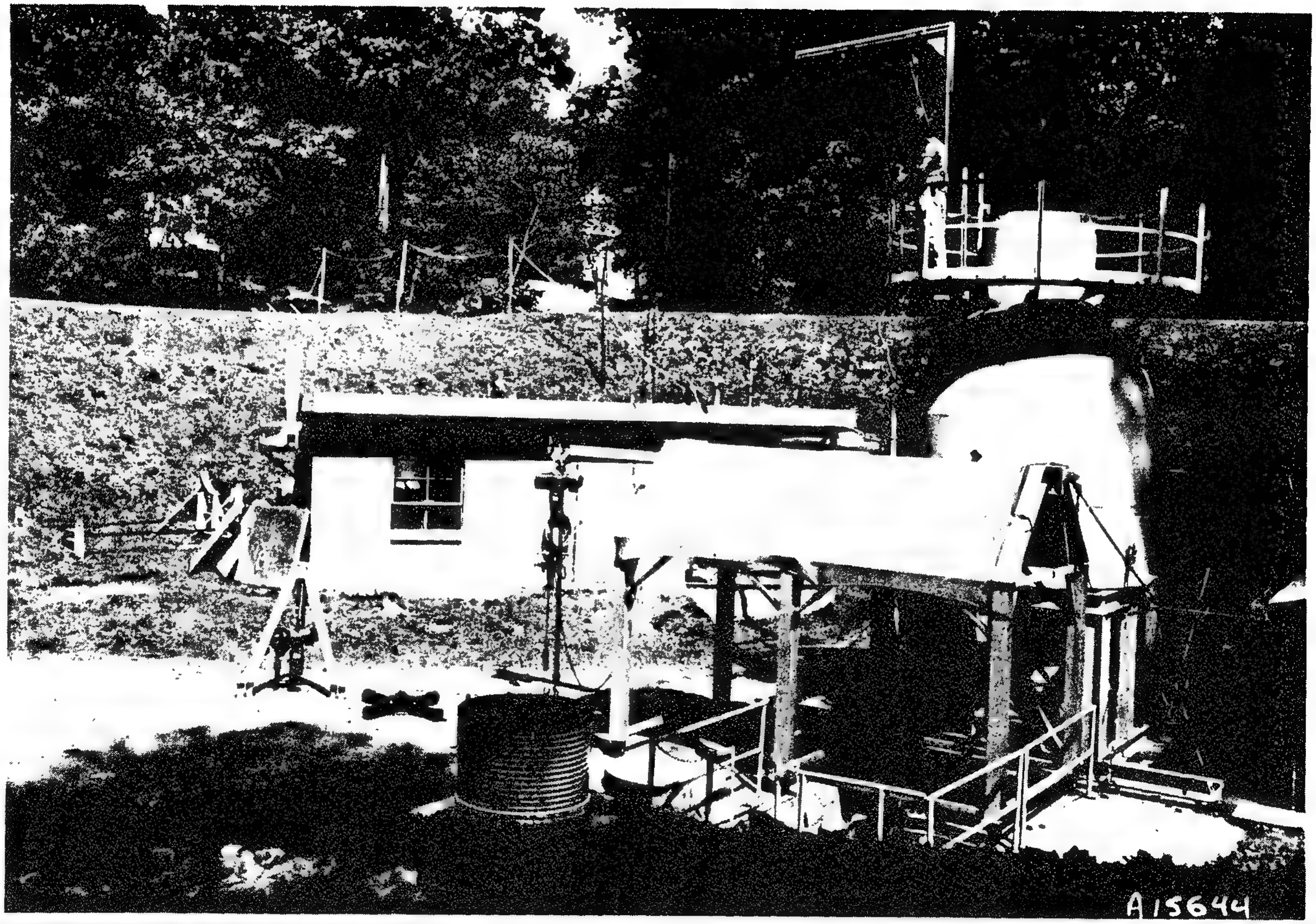


Figure 1-3. Photograph of the DNA/WES Ground Motion Test Facility. Note the man at the top of the gun for scale.

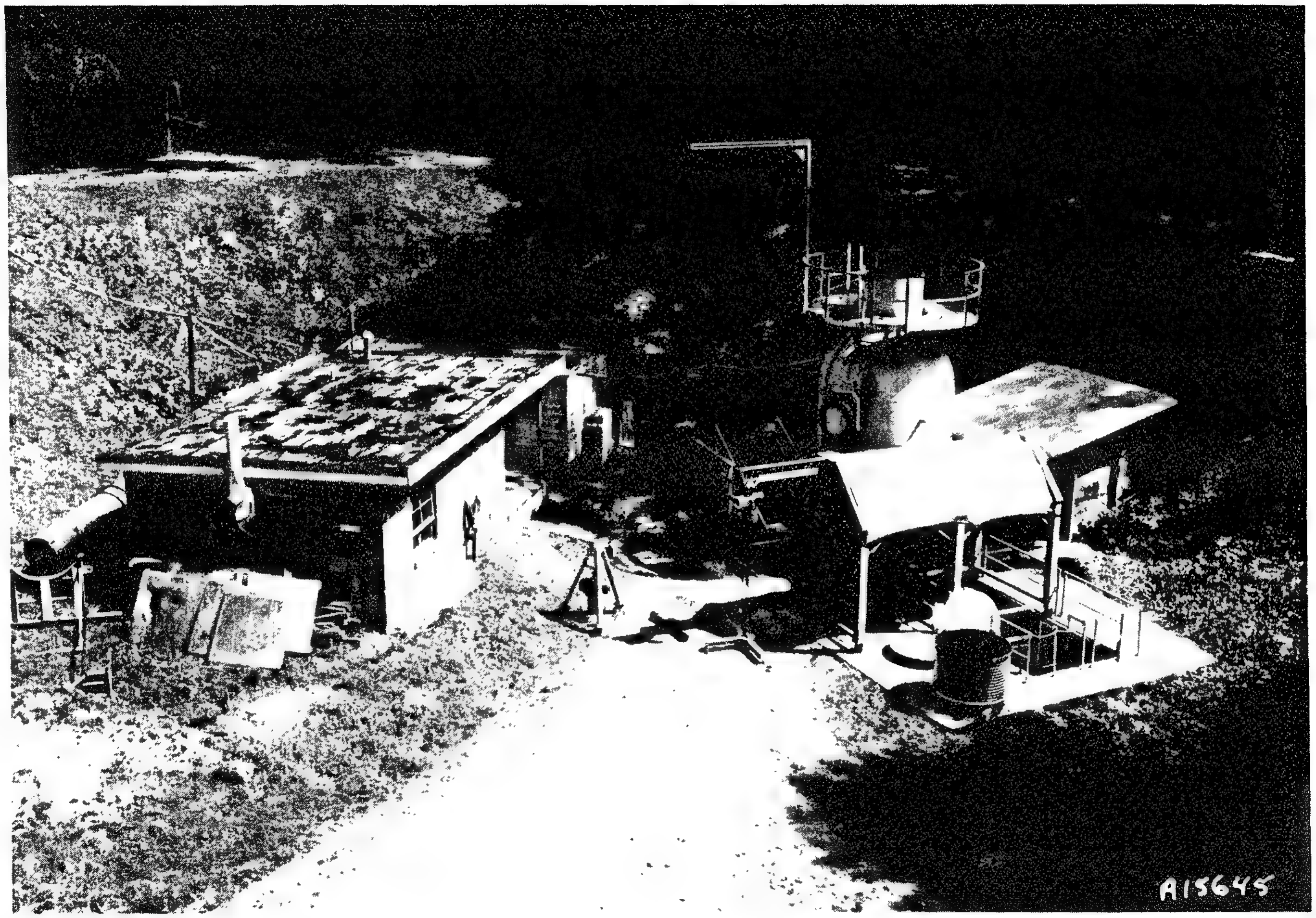


Figure 1-4. Photograph of the DNA/WES Ground Motion Test Facility. The cinder block building is a work room, and the shed contains various components of the fill system used in operating the 4-ft diameter gas gun.

SECTION 2

MATERIAL SELECTION AND TARGET CONSTRUCTION PROCEDURES

2.1 MATERIAL SELECTION.

Several factors were considered when choosing a soil material for use in a standardized target. One factor was the need for a long-term source for the material. An inexpensive and readily available material was preferred. The material must not pose a danger to personnel or the environment and should not require unusual handling or storage procedures. Also, a poorly-graded soil with few fines (clays and silts) was desirable. This type of material, with a majority of the grains identical in size, generally produces less variation in the as-placed density and is easy to handle.

The material chosen was F-75 Ottawa sand, available from U.S. Cilica in Ottawa, Illinois. The F-75 sand is one of the oldest product lines for U.S. Cilica. It is inexpensive (≈$350 per test) and requires about two weeks for delivery. The sand is packaged in 45-kg bags, which are shipped on pallets for ease of handling and to reduce storage problems.

Grain size analyses were conducted on the F-75 sand at the WES Geotechnical Laboratory. Presented in Figure 2-1 is a representative gradation curve for the sand. The steep slope of the gradation curve is indicative of a poorly-graded sand, i.e., there is little variation in the size of the particles. Grain sizes for this sand range from 0.038 mm to 0.600 mm in diameter. About 90 percent of the sand grains have a size ranging from 0.1 mm to 0.5 mm.

2.2 TARGET CONSTRUCTION PROCEDURES.

The first method attempted for placing the sand in a target used a pluviation (or raining) device. A schematic of the system is shown in Figure 2-2. Sand was first placed in the tank at the top of the device. The target container was positioned at least 1.3 m below the lower screening level. A lever was attached to a

plate located beneath the sand-filled tank. As the lever was pushed or pulled a series of holes was opened that allowed the flow of sand into the target. The rate of flow could be varied depending on which series of holes was opened and how far they were opened. After falling from the tank, the sand passed through two screens which randomly scattered the grains prior to their raining into the target container.

Historically, this method has provided a uniformly placed material in various types of testbeds (Arulmoli and Taylor, 1988). However, there were several problems using the device in this type of application. The disposable target container was a 1.4-m-diameter by 0.76-m-high corrugated 12-gauge steel pipe with a welded 12-gauge steel bottom. A uniform placement and flat surface was required across the entire diameter of the container. As the sand fell into the container, the flow was directed radially outward from the center of the container and upward at the sidewalls, creating an updraft and prohibiting the formation of a flat target surface. This phenomena occurred at even the slowest flow rates. Furthermore, the sand had be redistributed within the container to position instruments and to provide a cable egress. Once the sand was disturbed in the area around a gage, there was no assurance that the sand had the same density as originally placed. The only method of assuring the same density was to place the sand in a similar manner, and it was impossible to rain sand "beneath" a gage.

A vibratory placement method was attempted to overcome the problems experienced with the pluviation device. This method proved successful. Targets were constructed by placing four layers, or lifts, (typically 150-mm to 200-mm thick) of sand in the steel container. After a lift of sand was placed into the container, it was smoothed by hand to obtain a relatively level surface. A thin aluminum plate was placed over the layer of sand, and a vibratory compactor was used to pack the sand to a maximum density. A photograph of personnel operating the compactor is shown in Figure 2-3. By packing the material at its

maximum density, the material was less likely to change density as other lifts in the target were prepared or when the target was moved from the preparation area to its final location beneath the gun. The maximum density at which the material can be placed depends on the moisture content. It was recommended (Phillips, 1991), and confirmed, that the sand could be placed with a more uniform density if it was virtually dry, i.e., the moisture content was below 1 percent.

The density and moisture content were monitored during construction to determine the "quality" of the target. A target was considered to have a uniform density if the measured values were within ±0.02 Mg/m^3 of the average value for the entire target. A target was considered to have a uniform moisture content if the measured values were within ±0.3 percent of the average value for the target.

The wet density was measured at two locations in each lift of a target using a nuclear densitometer (see Figure 2-4). Several trials for gage placement were conducted to insure the consistency of the material density around a gage. For example, a layer of sand was vibrated, and the density was measured. A small section was excavated, and a gage was installed. An additional layer of sand was placed over the target surface and vibrated. The sand and gage were then gently excavated and the density beneath the gage was measured and compared with the original measurement. Similar values for the density were achieved, indicating that the sand beneath the gage had the same density as the material in other sections of the target. The change in gage elevation, due to the vibratory action, was also measured and found to be negligible (less than 2 mm).

The moisture content was measured at two locations in each lift by weighing samples of the sand before and after drying in a microwave oven, pictured in Figure 2-5. Several experiments were conducted to determine the proper power setting and drying time for the F-75 Ottawa sand. The two samples from each lift were dried simultaneously at a medium power setting for 12 minutes.

The references by Gilbert (1988 and 1990) contain more information on the use of a microwave oven for determining the moisture content of soils.

2.3 CONSTRUCTION OF TARGETS FOR TESTS 23, 24, AND 25.

Two depths in a target were instrumented on each test. These two depths (152 mm and 305 mm) included a variety of stress and velocity instruments. The stress gages included the Kulite Corporation High-Range SE (HRSE) Gage. The HRSE gage is a high-range version of the SE soil stress gage described in Ingram (1968). The ground-motion gages placed in the targets included the WES Wedge Canister (Welch, 1986), and the WES High-Fidelity Particle Velocity (HiFi) Gage (Welch et al., 1993). Both of these canisters contained Endevco Corporation accelerometers. The accelerometer in the Wedge Canister was mounted on a miniature shock-isolation system described in Welch and White (1987) and White (1989). Another type of ground-shock instrument used in the tests was the WES Stress and Velocity (S&V) Gage. This gage is a combination of the New Column-Based Stress (NCBS) and HiFi gages and measures both the normal stress and particle velocity with the same instrument package. The NCBS Gage is described in Welch, White, and King (1992); Welch (1993); and Rocco et al. (1994). Two developmental Fiber Optic Accelerometer packages from Geo-Centers, Inc. were included on one of the tests. A description of these gages and results from the test are reported by Landry, 1994.

The instruments were located in identical positions for each of the three tests in this series, with the exception of the accelerometers fielded by Geo-Centers, Inc. A schematic of the gage layout is presented in Figure 2-6. As-built locations for the instruments on Test 23, 24, and 25 are listed in Tables 2-1, 2-2, and 2-3, respectively. Complete test plans are reported in White (1993b); White (1993c); and White (1993d).

Gages were placed in the correct lift as the target was being built (see Figure 2-7). The instruments located at the

305-mm depth were placed at a radius of 152 mm from the vertical centerline of the target specimen, and the instruments at the 152-mm depth were placed at a radius of 305 mm. A single gage was included in the center of the target at the lower instrumented depth. The tests also included piezoelectric crystals, spaced every 76 mm through the depth of the target, to mark the time-of-arrival (TOA) of the loading wave as it propagated through the target. Shown in the photograph of Figure 2-8 are instruments located at the 305-mm depth in a target. The large instrument in the center is the S&V gage. Spaced at a 152-mm radius from the central gage is a HiFi gage, a TOA crystal, and a HRSE gage (starting from the left and looking clockwise). A short length of cable was routed from each gage, through the target, and terminated just outside of the target container. The instrument cables can be seen in the photograph of a completed target in Figure 2-9. The total depth of each target was approximately 610 mm.

Density and moisture content profiles through the depth of the target for the three tests in this series (Tests 23, 24, and 25) are presented in Figures 2-10 through 2-12. The values presented in the figures represent the average of two measurements at each depth. The consistency of the density, both through the depth of the target and from target to target (1.75, 1.74, and 1.76 Mg/m^3), indicates that the vibratory placement procedure is a reliable method for repeatedly constructing standardized targets. Of course, the consistency of the density is dependent upon the moisture content, which for these targets was intentionally kept very low: 0.19, 0.24, and 0.28 percent for Tests 23, 24, and 25, respectively.

The time required to build a target, once all materials were on hand (gages, sand, vibrator, microwave oven, tools, etc.), was approximately one and one-half days per test. All of the targets were prepared in a sheltered area on successive days. The targets were moved to the gas gun facility, as required for testing, using a fork lift.

In addition to the target instrumentation, several types of diagnostic measurements were included on each test. A single pressure gage, located in the reservoir of the gas gun, was used to monitor system pressure prior to firing at the control panel for the gun. Six piezoelectric pins (Dynasen, 1993) at the bottom of the barrel of the gun were used to measure the projectile velocity and planarity as the forward face exited the barrel. The closure of the projectile onto the target was monitored using Dynasen CA-1043 self-shorting pins and CA-1136 piezoelectric pins. The pins were placed in time-of-arrival pin jigs at various locations about the surface of the target (see Figure 2-9). A schematic of a pin jig is shown in Figure 2-13. Cables were glued into the back-side of the jig such that, when the 76-mm long pins were placed in their sockets, the final heights of the pins were "stair-stepped." This allowed for several measurements of the projectile position just prior to impact. A video camera was used to photograph each test.

2.4 TESTING PROCEDURE.

The projectile for each test was assembled prior to loading it into the barrel of the gas gun. The configuration of the projectile was identical for each of the three tests reported here, i.e., a 175-mm thickness of energy-absorbing foam (Henry, 1991) was sandwiched between the carriage and the 50-mm-thick steel impact plate. The mass of the projectile for these tests was 1,480 kg. The projectile was raised into its cocked position via a chain hoist attached to a tripod at the top of the barrel. Two chains were used to lift the projectile, and two were used as safety chains during the loading process.

After the projectile was loaded into the gun and secured with safety chains, sand was placed over the earthen portion of the trench bottom located directly beneath the barrel of the gun. Several timbers were placed in the sand base to support the target (see Figure 2-14). The target was moved into position beneath the barrel of the gun via a trolley that ran along

channels cast into the concrete walls on either side of the trench. The target was centered beneath the gun using a plumb bob suspended from temporary crosshairs at the bottom of the barrel. Final leveling of the target was achieved using a carpenter's level to guide placement of shims between the steel bottom of the target and the timbers. The surface of the target was typically located about 1.2 m below the end of the barrel, allowing the entire projectile to exit the barrel prior to impact. An advantage of supporting the target with timbers is that it essentially provided a "free" surface at its base. The shock wave reflecting off this free surface is identifiable in the stress and velocity wave forms, and thus may be used to investigate the relief wave speed of the target material.

After the target was positioned beneath the gun, instrument cables were spliced to cables running to the Control Trailer. When all electrical checkouts were completed, the safety chains on the projectile were removed. A 1-mm-thick fiberglass diaphragm and a plastic liner, used for containing the water reaction mass, were placed above the quick-release trigger mechanism in the upper portion of the barrel. The depth of the water reaction mass for all tests was about 1.35 m, which corresponds to a mass of 1,570 kg. After placing the reaction mass, the firing system for the trigger mechanism was enabled by supplying pressurized gas to the system and by connecting battery power to a solenoid valve used to control the flow of gas. Prior to clearing the test site, water was supplied to the in-line aftercooler in the pressure system, and the video camera(s) were started.

Instrument recording and remote operation of the gun were performed at the Control Trailer, located approximately 53 m from the gun. The trailer can be seen in the background of Figure 1-3. A photograph of the recording equipment is shown in Figure 2-15. The control panel used for operating the "fill system" for the gun is shown in Figure 2-16. The fill system (illustrated in Figure 2-17) is comprised of three components:

the pressure system, the vacuum system, and the firing system. None of the tests reported here used a vacuum in the lower section of the barrel. The pressure vessel was filled by a high-pressure, high-volume air compressor. After the desired testing level was reached, the air compressor was stopped. The vessel pressure for Tests 23, 24, and 25 was 869, 869, and 876 kPa, respectively.

The time required to pressurize the gun for each test was approximately 35 minutes. A master switch was then used to ensure all components of the pressure system were in their proper state, i.e., all valves closed and the air compressor shut off. The master switch also provided power to the firing system. After sounding a warning siren and completing a final check with instrumentation personnel, the gun was fired by energizing the 4-way solenoid valve in the firing system. The action of the valve allowed gas pressure to activate the quick-release trigger mechanism, which released the projectile.

The time required to prepare the gun for testing, position the target beneath the gun, complete electrical connections and instrumentation setup, conduct the test and clean-up was approximately two days.

Table 2-1. Gage locations for Test 23.				
Gage Type	Gage Name	θ Degrees	Range mm	Depth[1] mm
TOA Crystal	TOA-3	0	51	75
TOA Crystal	TOA-6	90	51	151
TOA Crystal	TOA-9	180	152	228
TOA Crystal	TOA-12	270	152	305
TOA Crystal	TOA-15	0	51	302
TOA Crystal	TOA-18	90	51	459
TOA Crystal	TOA-21	180	51	532
TOA Crystal	TOA-24	270	51	609
S&V[2]	S&VS-1[3]	180	305	142
	S&VA-1[4]	180	305	142
HRSE Stress	HRSE-1A	90	305	143
HRSE Stress	HRSE-1B	270	305	146
WEDGE CAN Accel.	AVW-1	0	305	124
S&V[5]	S&VS-2[3]	90	25	294
	S&VA-2[4]	270	30	294
HRSE Stress	HRSE-2	45	153	298
HIFI Accel.	HIFI-2	225	153	293
TOA Pin Jig[6]	TOA-01-0	180	51	-0.3
	TOA-01-5	-	-	-14.1
	TOA-01-15	180	70	-40.3
	TOA-01-25	-	-	-64.0
TOA Pin Jig[6]	TOA-02-0	0	457	-0.2
	TOA-02-5	-	-	-15.1
	TOA-02-15	0	476	-40.5
	TOA-02-25	-	-	-65.3

Table 2-1. Gage locations for Test 23. (Continued)				
Gage Type	Gage Name	θ Degrees	Range mm	Depth[1] mm
TOA Pin Jig[6]	TOA-03-0	120	457	-0.4
	TOA-03-5	-	-	-15.2
	TOA-03-15	120	476	-40.1
	TOA-03-25	-	-	-65.9
TOA Pin Jig[6]	TOA-04-0	240	457	-0.3
	TOA-04-5	-	-	-14.3
	TOA-04-15	240	476	-33.3
	TOA-04-25	-	-	-64.9

1 Depth to top of instrument, positive depth is into the target material.

2 Center of S&V gage body at 305 mm radius, 180°.

3 Stress sensor.

4 Acceleration sensor.

5 Center of S&V gage body at 305 mm depth, center of target.

6 The -0 and -15 pin holes were used to position the TOA pin jigs in the target.

Table 2-2. Gage locations for Test 24.

Gage Type	Gage Name	θ Degrees	Range mm	Depth[1] mm
TOA Crystal	TOA-3	0	51	62
TOA Crystal	TOA-6	90	51	138
TOA Crystal	TOA-9	180	152	215
TOA Crystal	TOA-12	270	152	305
TOA Crystal	TOA-15	0	51	367
TOA Crystal	TOA-18	90	51	450
TOA Crystal	TOA-21	180	51	526
TOA Crystal	TOA-24	270	51	596
S&V[2]	S&VS-1[3]	180	305	127
	S&VA-1[4]	180	305	127
HRSE Stress	HRSE-1A	90	305	132
HRSE Stress	HRSE-1B	270	305	132
WEDGE CAN Accel.	AVW-1	0	305	112
S&V[5]	S&VS-2[3]	90	25	280
	S&VA-2[4]	270	30	280
HRSE Stress	HRSE-2	45	153	285
HIFI Accel.	HIFI-2	225	153	279
TOA Pin Jig[6]	TOA-01-0	180	51	-0.2
	TOA-01-5	-	-	-8.8
	TOA-01-15	180	70	-32.4
	TOA-01-25	-	-	-65.4
TOA Pin Jig[6]	TOA-02-0	0	457	-0.2
	TOA-02-5	-	-	-16.2
	TOA-02-15	0	476	-41.2
	TOA-02-25	-	-	-67.3

Table 2-2. Gage locations for Test 24. (Continued)				
Gage Type	Gage Name	θ Degrees	Range mm	Depth[1] mm
TOA Pin Jig[6]	TOA-03-0	120	457	-0.2
	TOA-03-5	-	-	-13.7
	TOA-03-15	120	476	-37.6
	TOA-03-25	-	-	-62.8
TOA Pin Jig[6]	TOA-04-0	240	457	-0.2
	TOA-04-5	-	-	-15.2
	TOA-04-15	240	476	-39.4
	TOA-04-25	-	-	-64.7

1 Depth to top of instrument, positive depth is into the target material.

2 Center of S&V gage body at 305 mm radius, 180°.

3 Stress sensor.

4 Acceleration sensor.

5 Center of S&V gage body at 305 mm depth, center of target.

6 The -0 and -15 pin holes were used to position the TOA pin jigs in the target.

Table 2-3. Gage locations for Test 25.				
Gage Type	Gage Name	θ Degrees	Range mm	Depth[1] mm
TOA Crystal	TOA-3	0	51	72
TOA Crystal	TOA-6	90	51	148
TOA Crystal	TOA-9	180	152	224
TOA Crystal	TOA-12	270	152	300
TOA Crystal	TOA-15	0	51	379
TOA Crystal	TOA-18	90	51	453
TOA Crystal	TOA-21	180	51	528
TOA Crystal	TOA-24	270	51	606
S&V[2]	S&VS-1[3]	180	305	138
	S&VA-1[4]	180	305	138
HRSE Stress	HRSE-1A	90	305	142
HRSE Stress	HRSE-1B	270	305	143
WEDGE CAN Accel.	AVW-1	0	305	122
S&V[5]	S&VS-2[3]	90	25	290
	S&VA-2[4]	270	30	290
HRSE Stress	HRSE-2	45	153	296
HIFI Accel.	HIFI-2	225	153	290
TOA Pin Jig[6]	TOA-01-0	180	51	-0.1
	TOA-01-5	-	-	-14.5
	TOA-01-15	180	70	-39.0
	TOA-01-25	-	-	-63.4
TOA Pin Jig[6]	TOA-02-0	0	457	-0.1
	TOA-02-5	-	-	-13.4
	TOA-02-15	0	476	-40.2
	TOA-02-25	-	-	-65.0

Table 2-3. Gage locations for Test 25. (Continued)				
Gage Type	Gage Name	θ Degrees	Range mm	Depth[1] mm
TOA Pin Jig[6]	TOA-03-0	120	457	-0.1
	TOA-03-5	-	-	-14.4
	TOA-03-15	120	476	-37.8
	TOA-03-25	-	-	-64.9
TOA Pin Jig[6]	TOA-04-0	240	457	-0.2
	TOA-04-5	-	-	-14.6
	TOA-04-15	240	476	-26.8
	TOA-04-25	-	-	-65.4

1 Depth to top of instrument, positive depth is into the target material.

2 Center of S&V gage body at 305 mm radius, 180°.

3 Stress sensor.

4 Acceleration sensor.

5 Center of S&V gage body at 305 mm depth, center of target.

6 The -0 and -15 pin holes were used to position the TOA pin jigs in the target.

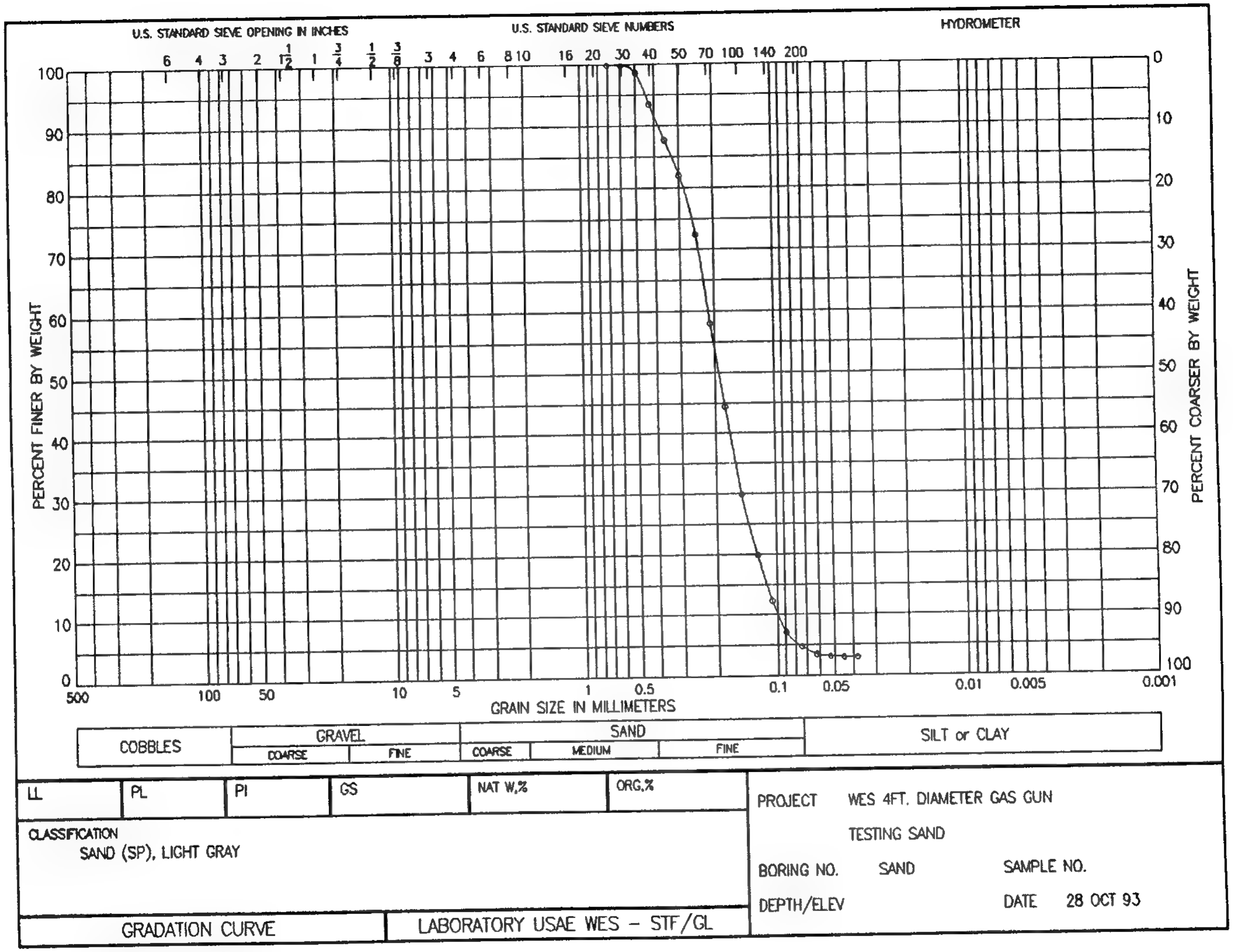


Figure 2-1. Gradation curve for Ottawa F-75 sand.

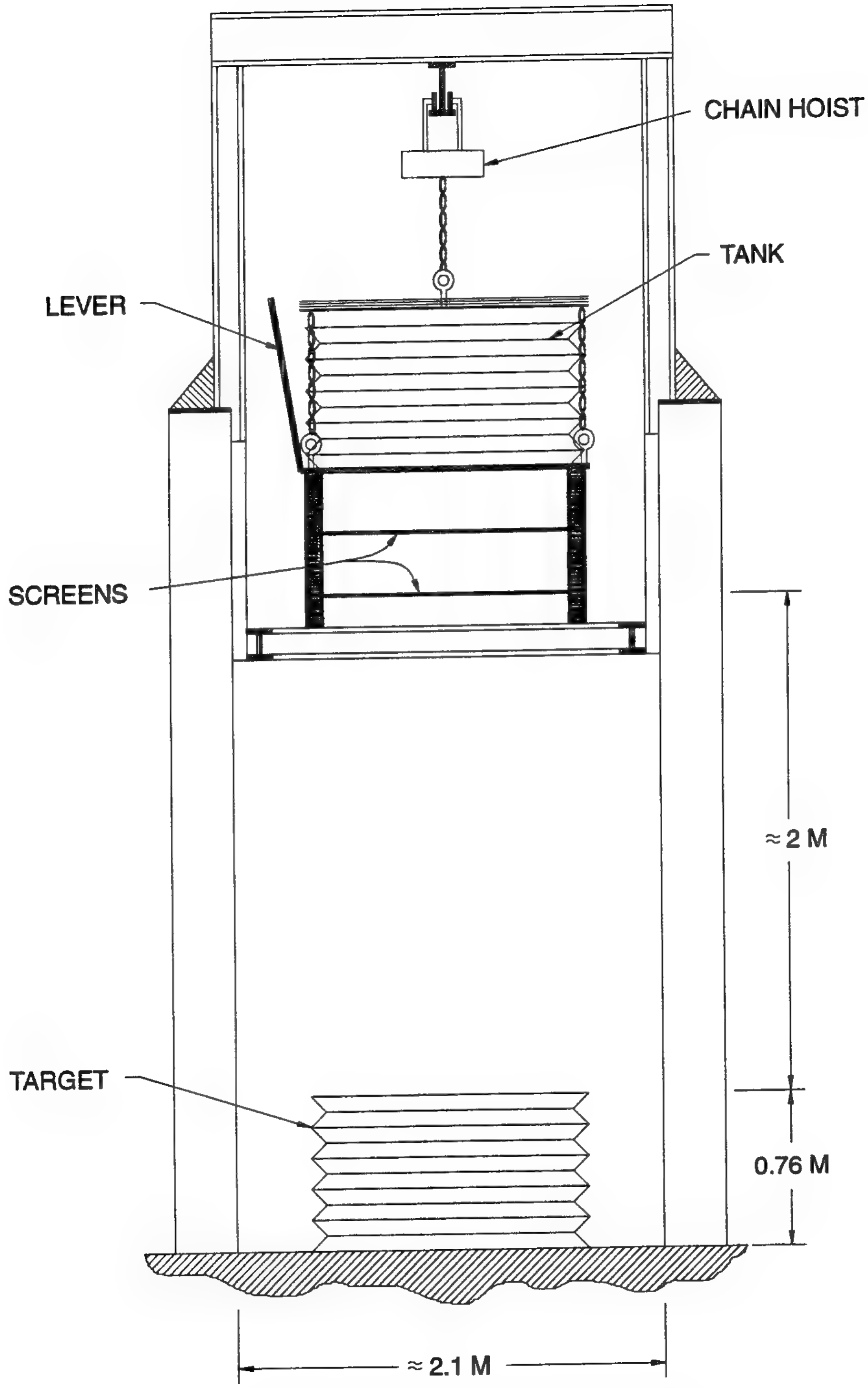


Figure 2-2. Schematic of the pluviation system.

Figure 2-3. Photograph of personnel vibrating a lift of sand.

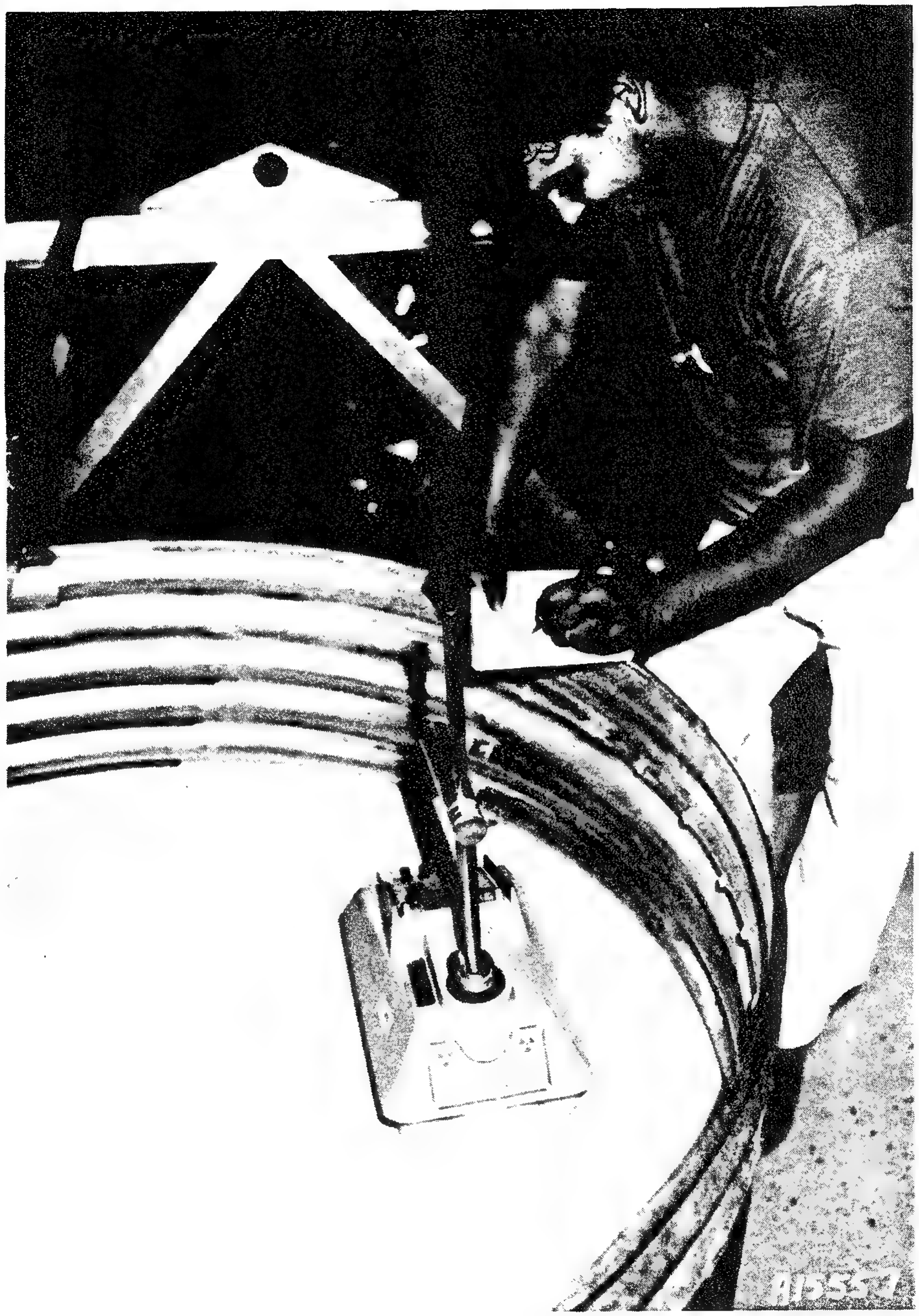


Figure 2-4. Photograph of the nuclear densitometer used to measure density through each lift of the target.

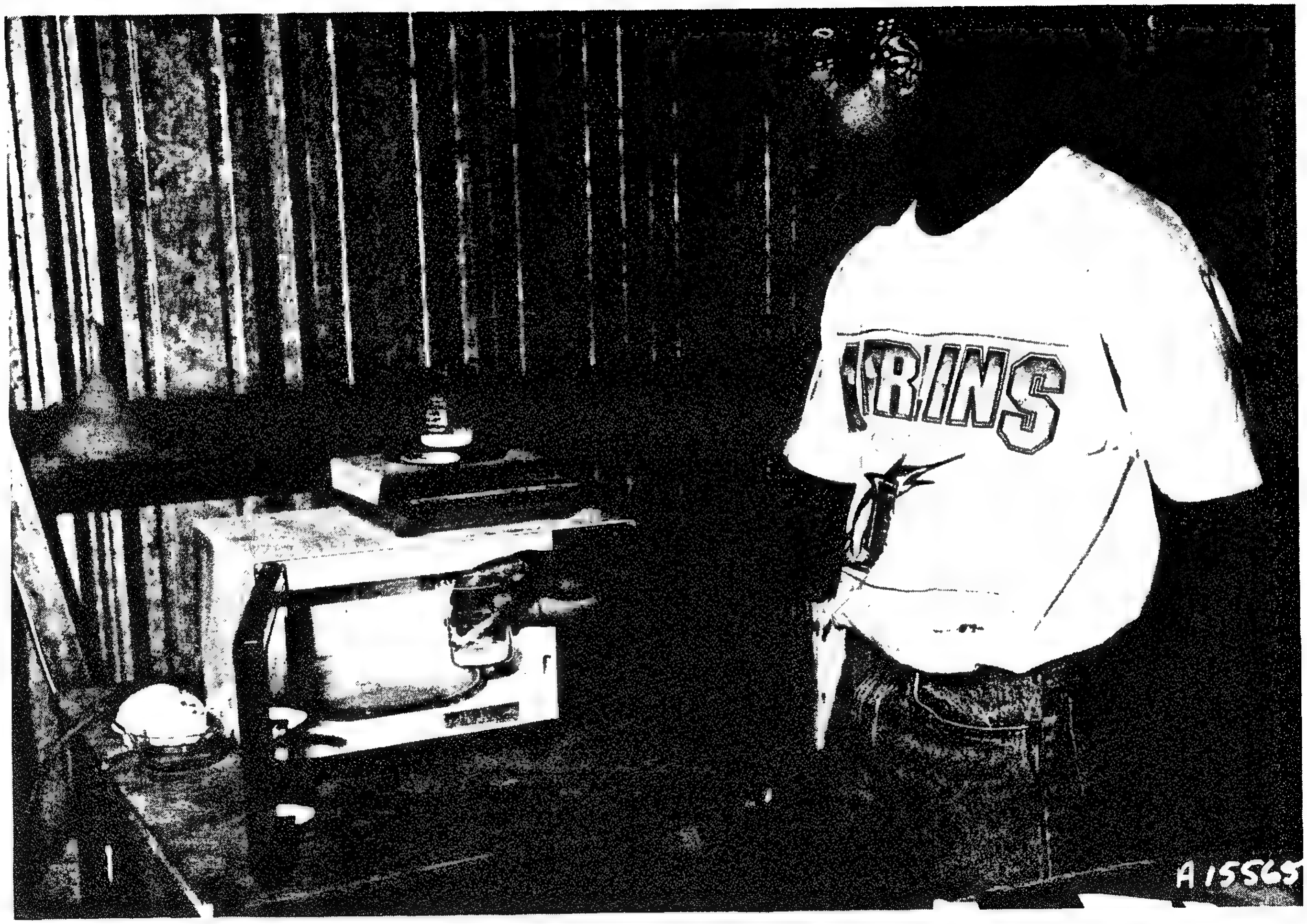


Figure 2-5. Photograph of personnel using a microwave oven to determine the moisture content of each lift of sand.

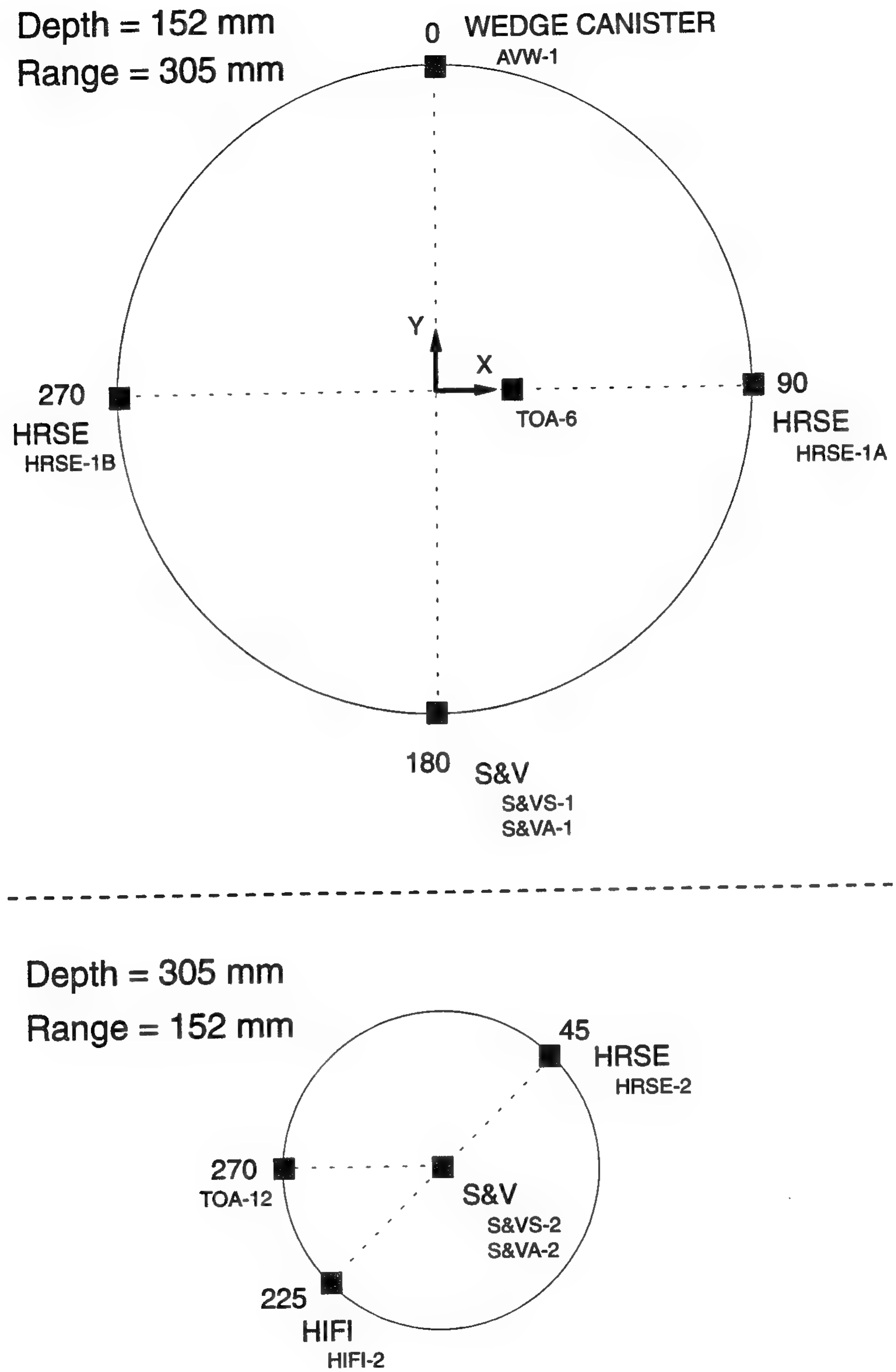


Figure 2-6. Typical layout for target instrumentation.

Figure 2-7. Photograph of personnel placing gages in the target.

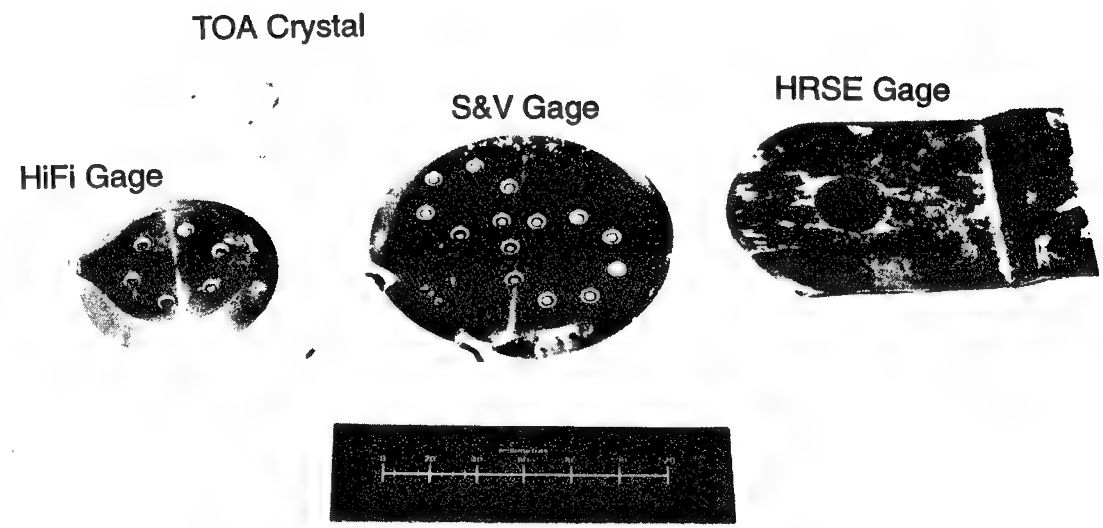


Figure 2-8. Stress, velocity, and TOA gages located at the 305 mm depth in a target.

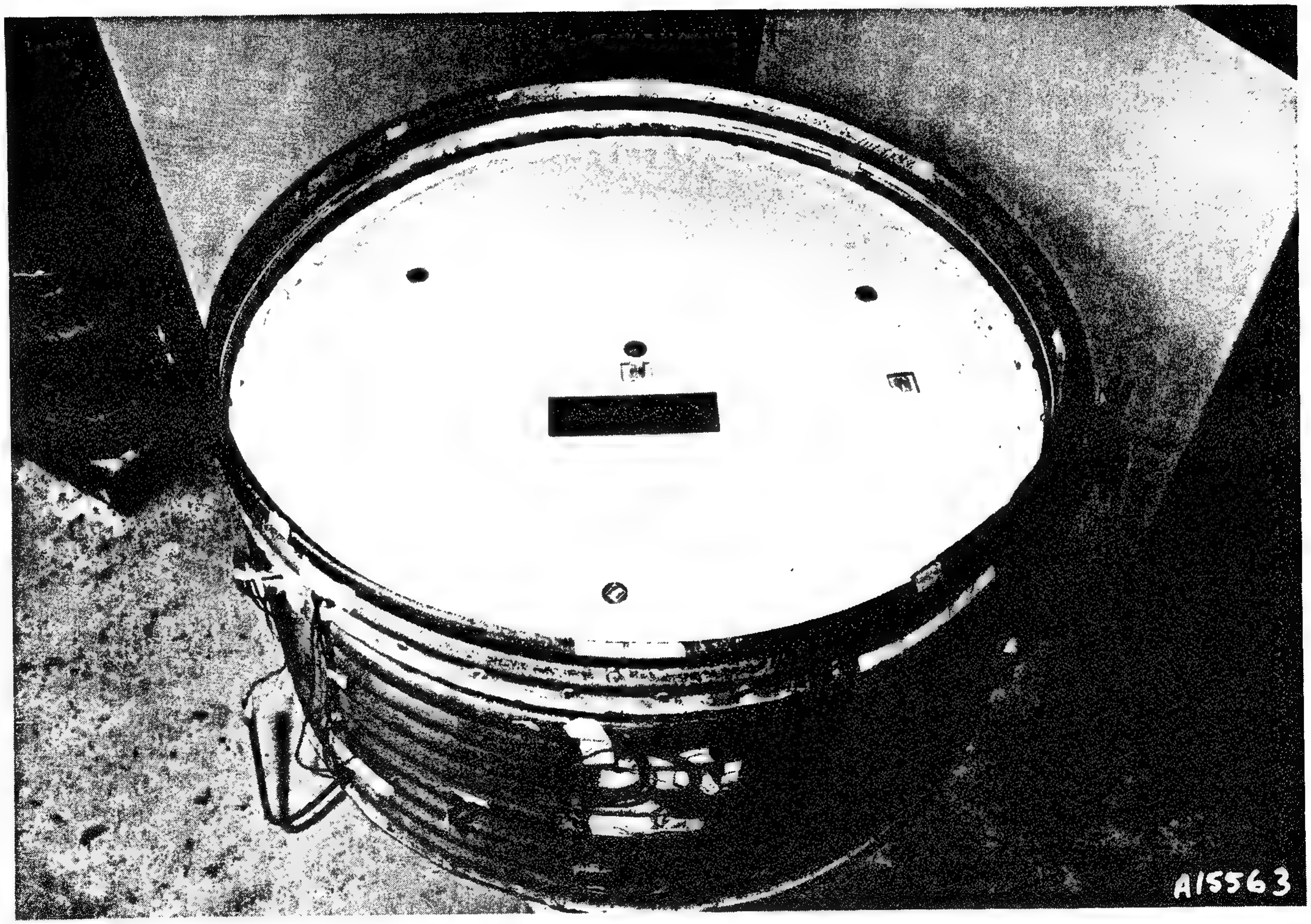
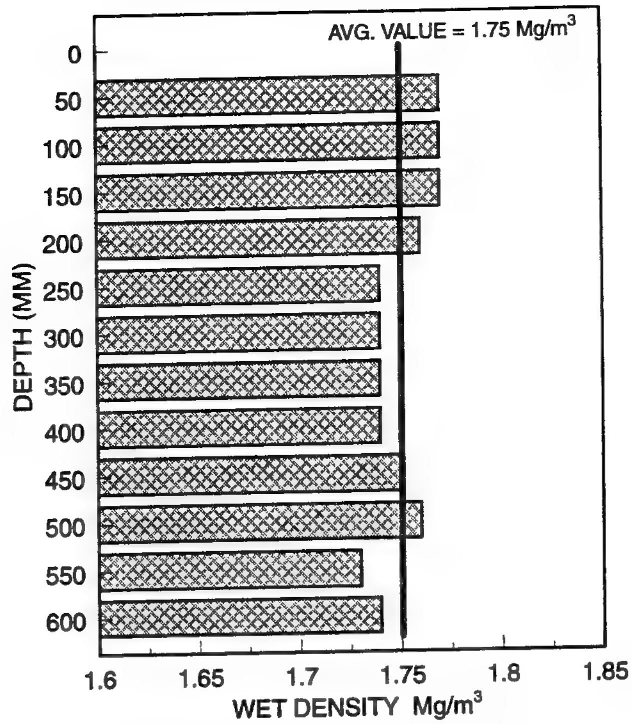
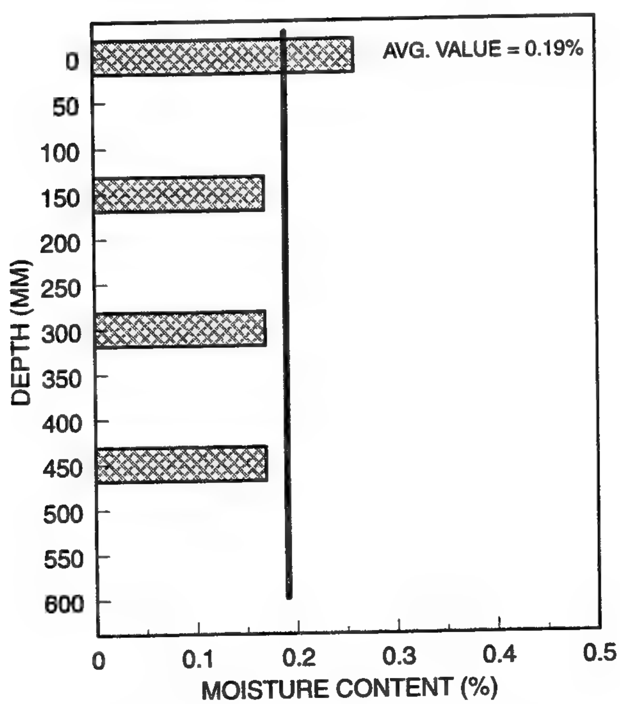


Figure 2-9. A completed target, ready to be relocated to the testing area. Note: the circular gages at the surface receive piezoelectric pins used to measure impact velocity and planarity.

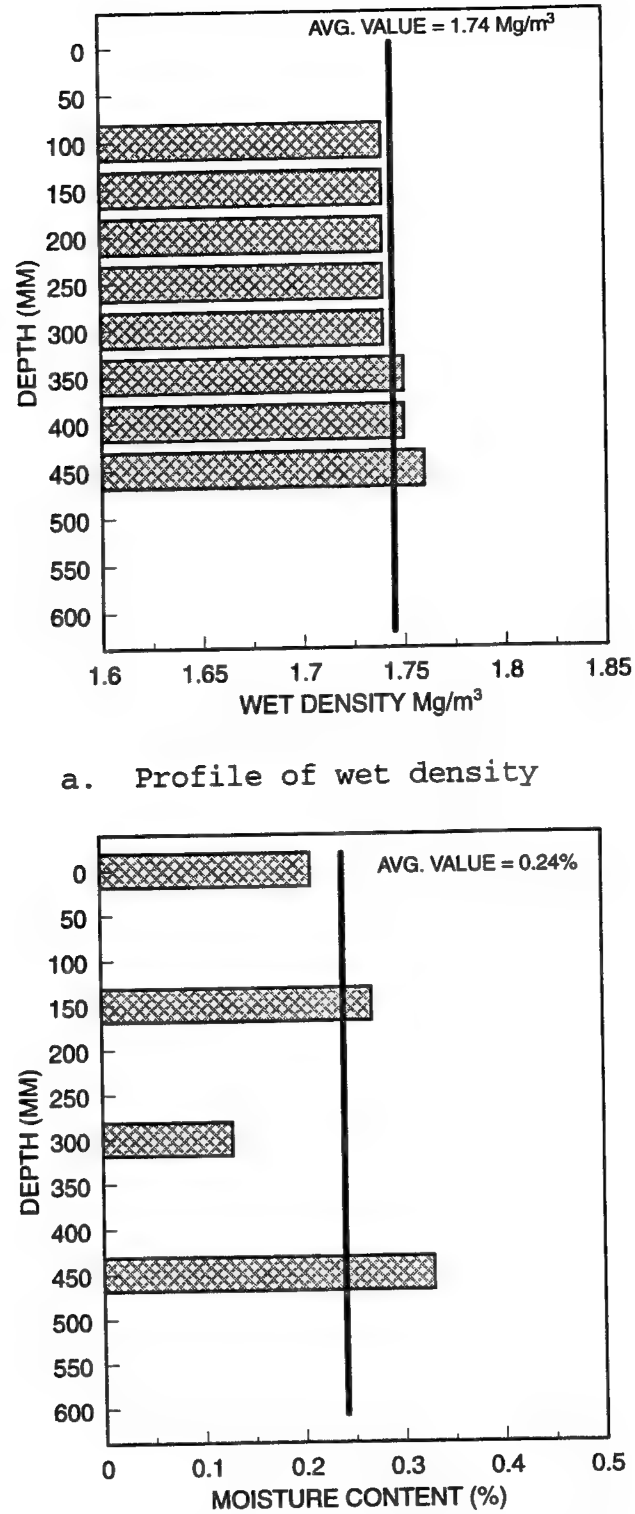


a. Profile of wet density



b. Profile of moisture content

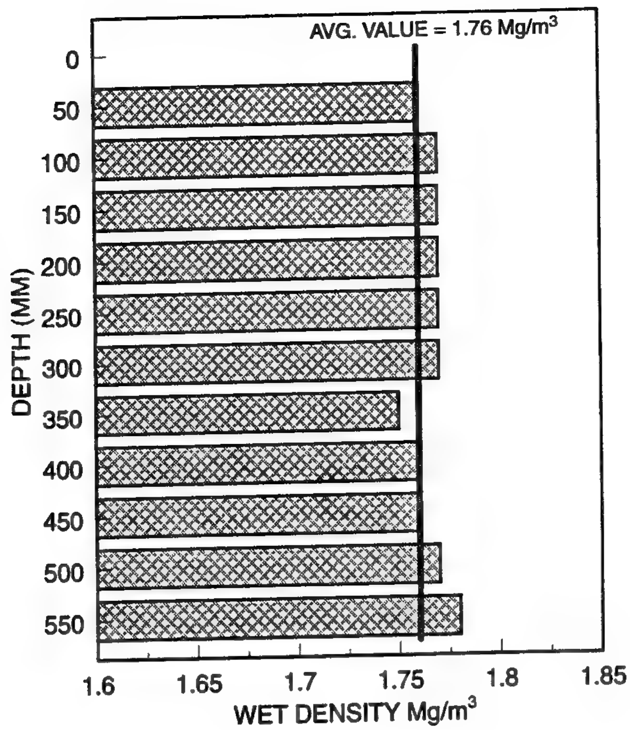
Figure 2-10. Density and moisture content profiles for Test 23.



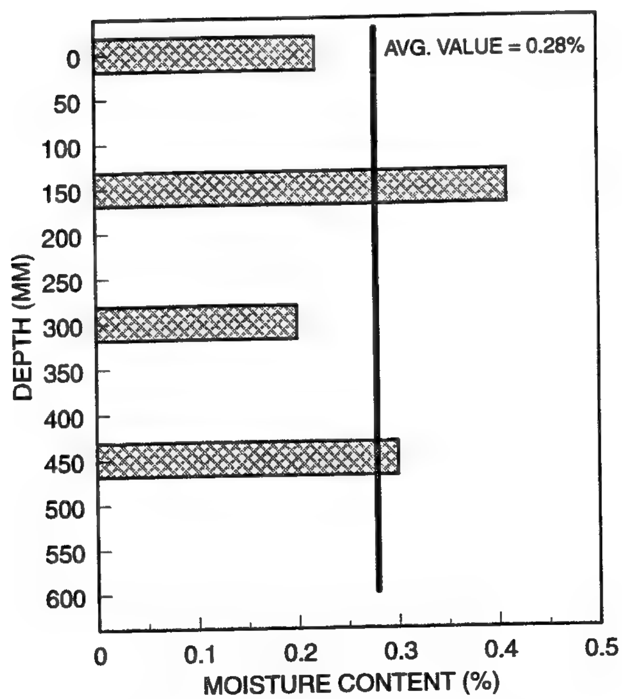
a. Profile of wet density

b. Profile of moisture content

Figure 2-11. Density and moisture content profiles for Test 24.



a. Profile of wet density



b. Profile of moisture content

Figure 2-12. Density and moisture content profiles for Test 25.

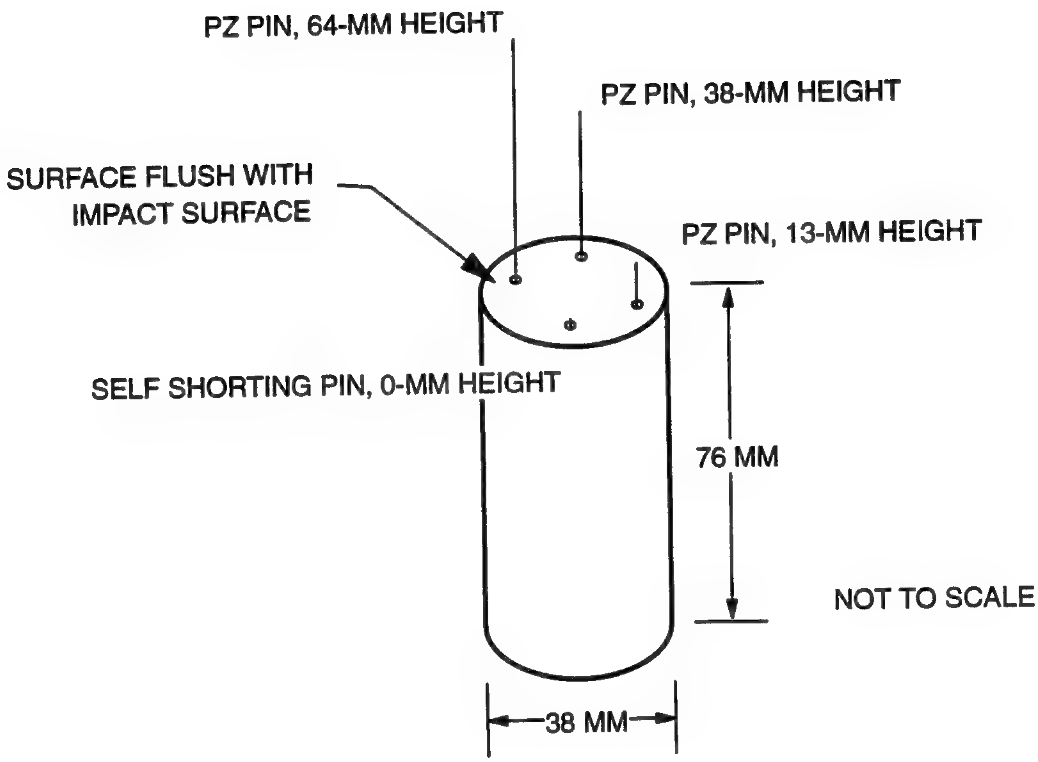


Figure 2-13. Schematic of the TOA Pin Jig used to house piezoelectric pins that measured the closure of the projectile onto the target Test 25.

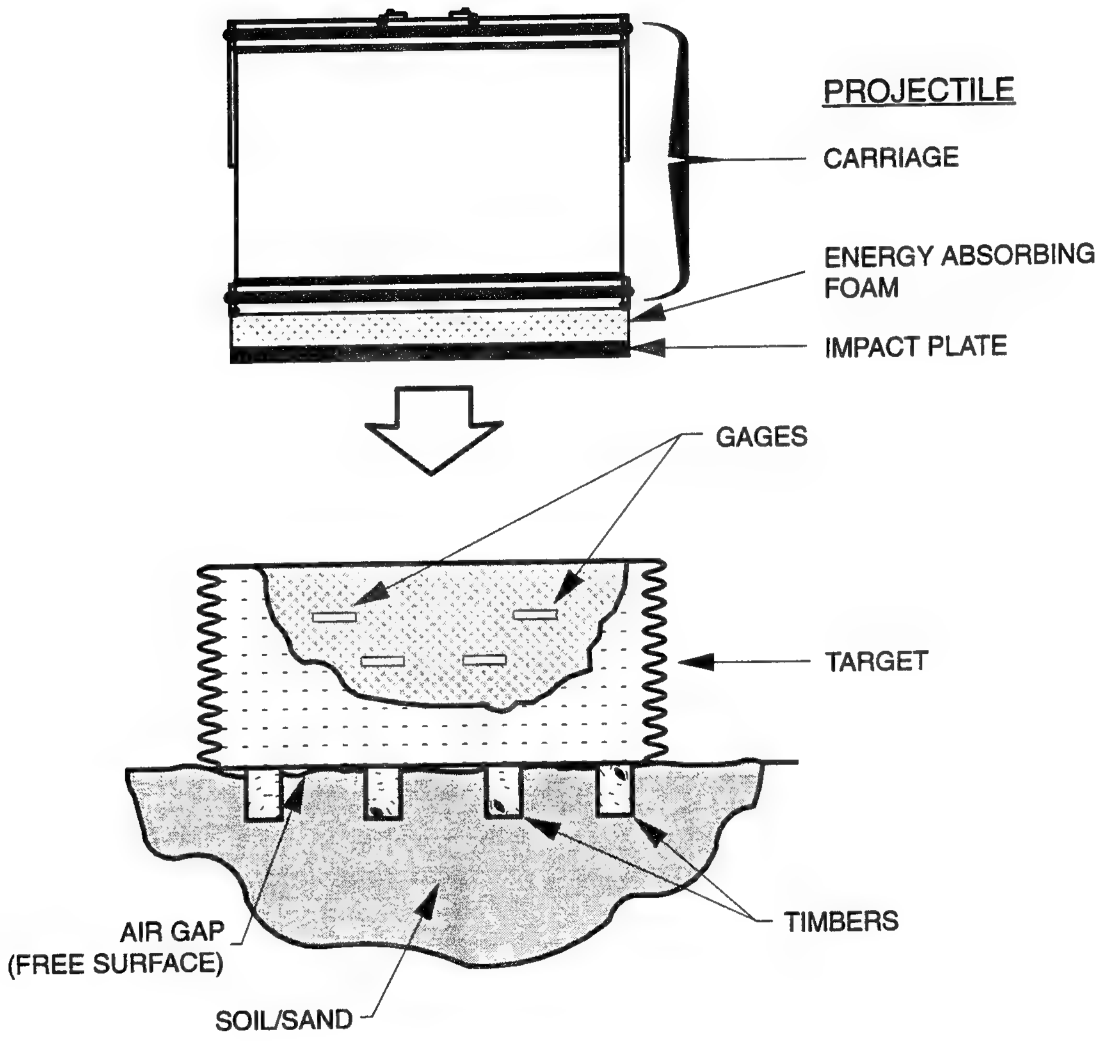


Figure 2-14. Cross-section of the gas gun projectile and container of target material.

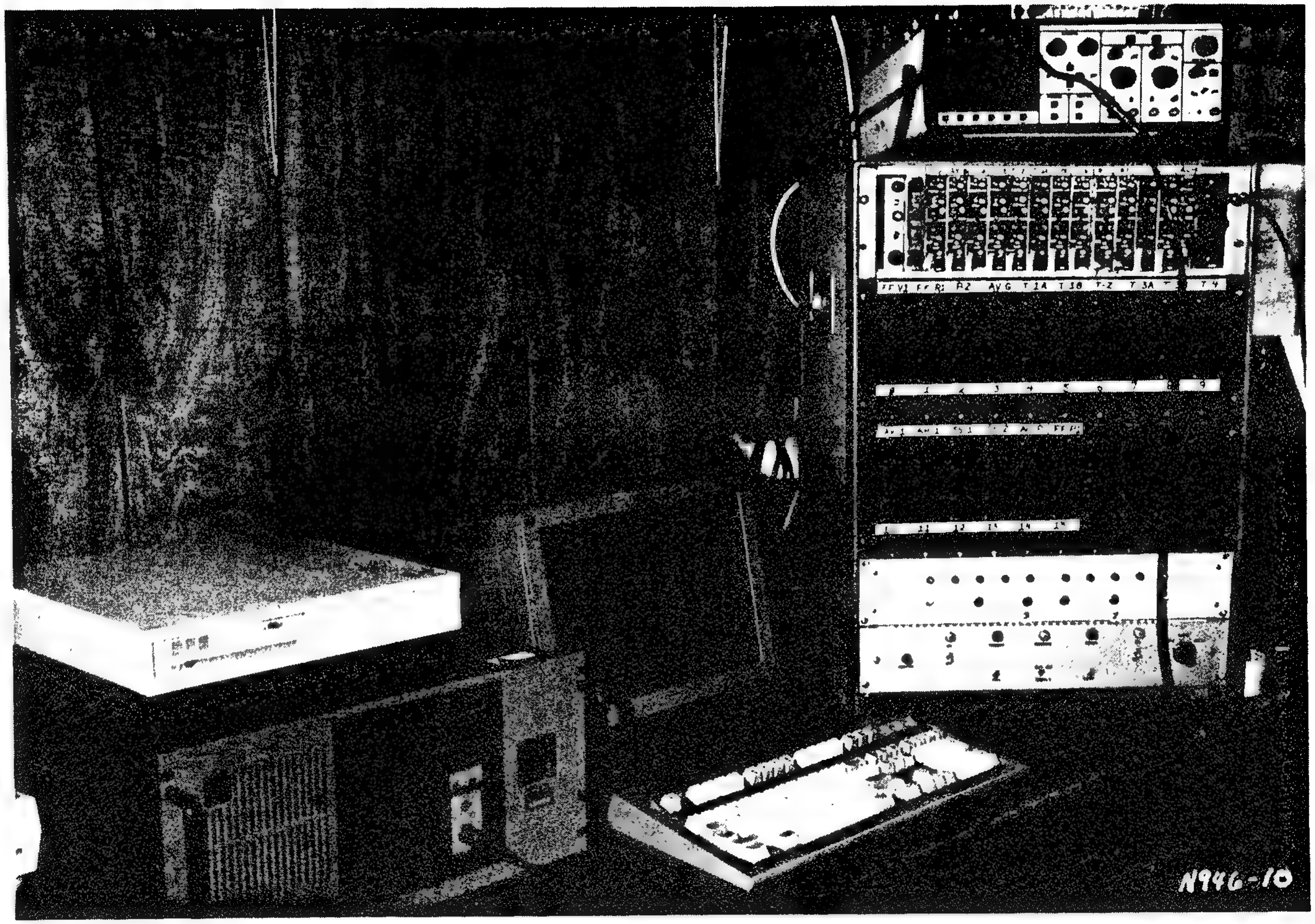


Figure 2-15. Recording equipment used for tests with the gas gun.

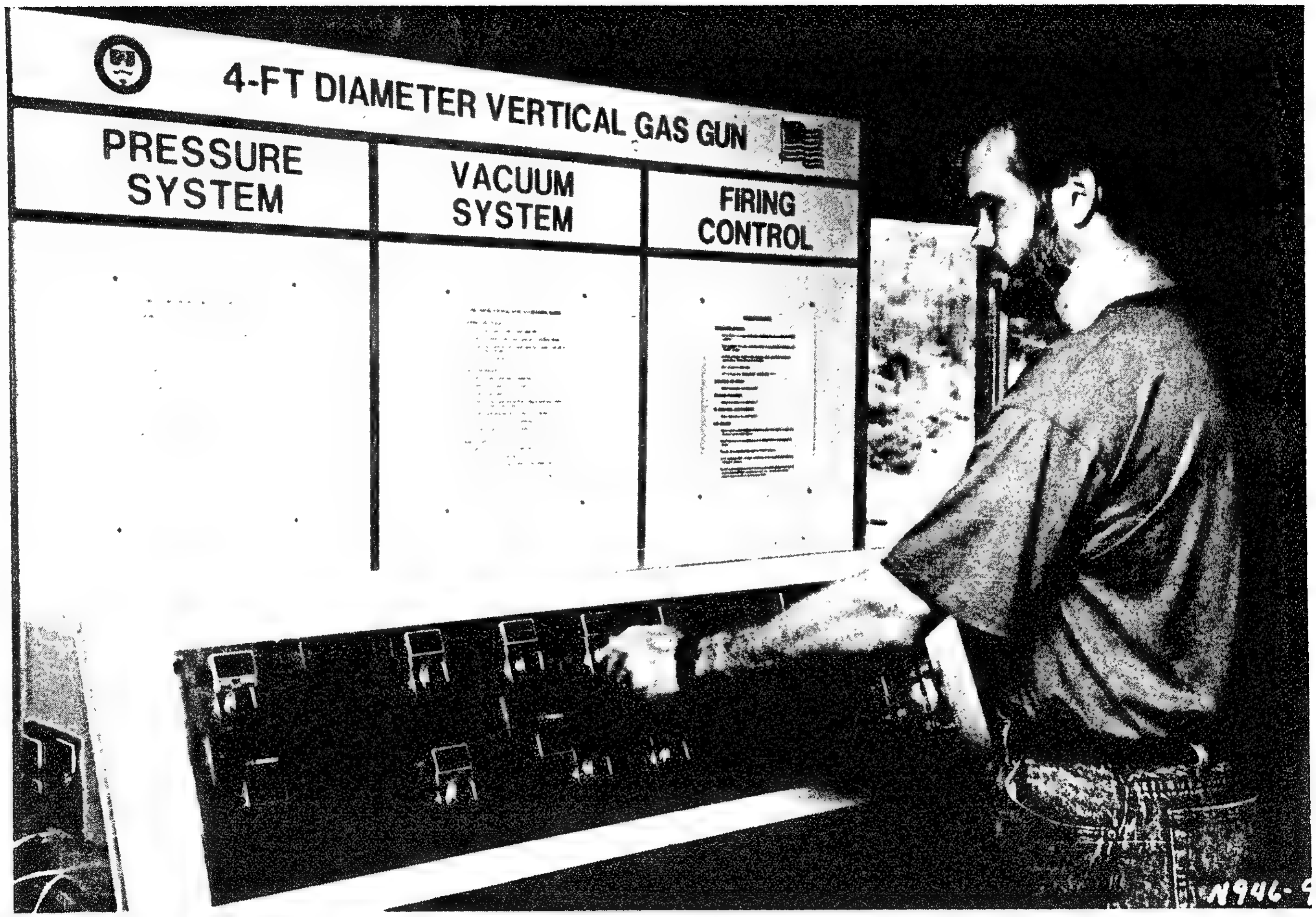


Figure 2-16. Control panel used for operating the gas gun.

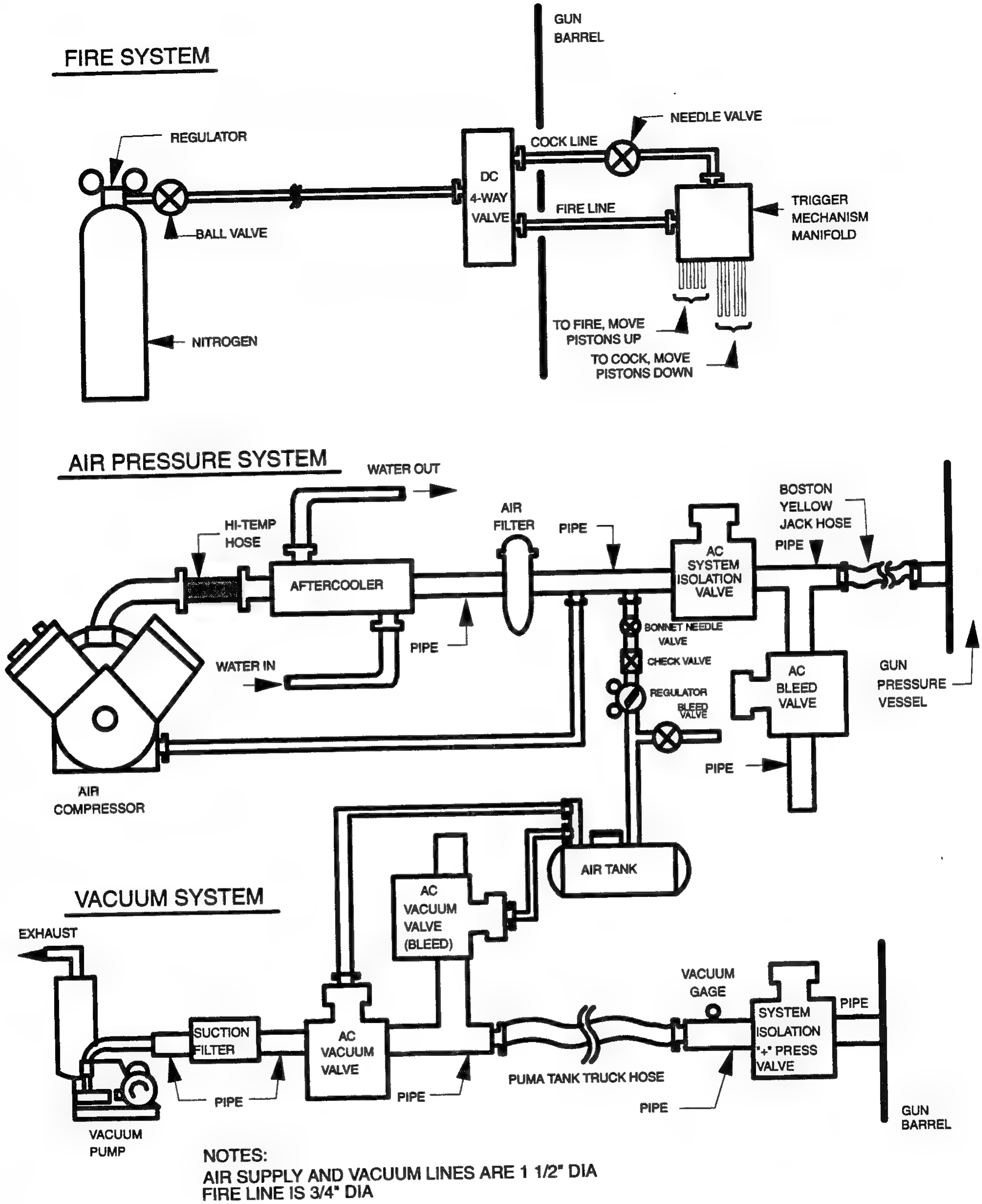


Figure 2-17. Schematic of the fill system used for conducting tests with the gas gun.

SECTION 3

RESULTS FROM IDENTICAL TESTS WITH THE GAS GUN

3.1 IMPACT VELOCITY.

The closure of the projectile onto the target was monitored using Dynasen CA-1043 self-shorting pins and CA-1136 piezoelectric pins. The nominal heights of the pins above the target surface were 0 mm, 13 mm, 38 mm, and 64 mm (see Figure 2-13). The piezoelectric pins were placed at locations above the target surface, and the self-shorting pins were located at the surface. The performance of the self-shorting pins in measuring the time of impact was marginal. This was most likely the result of being slightly below the jig surface in several instances, thus prohibiting impact onto the pin.

Figure 3-1 is a plot of the TOA versus pin height (above the target surface) for Test 23. The inverse slope of the best linear fit through the data is reported as the impact velocity, or for this test, 49.7 m/sec. Figures 3-2 and 3-3 are similar plots of TOA versus pin height for Tests 24 and 25, respectively. The impact velocity for these tests was determined to be 50.2 and 50.4 m/sec, within about 1 percent of the first test.

The ability to consistently provide the same input (i.e., identical projectile velocity) to a target is crucial for gage validation tests and was thus satisfactorily achieved by the gas gun.

3.2 TARGET DIAGNOSTIC INSTRUMENTATION.

Some fundamental properties of a material may be determined from time-of-arrival (TOA) measurements made in a gas gun target. By knowing the location of instruments in a target before and during the test, and by knowing the time of initial loading-wave and relief-wave arrival at the instrument location, the propagation velocity of a loading wave and a relief wave traveling through the material may be derived. The sections

below describe how the TOA data and gage records were used to determine these material properties.

3.2.1 Propagation Velocity of Loading Wave.

The TOA of the shock wave at each instrument was determined from the wave form recorded by the instrument. In addition to stress and velocity instruments in the target, piezoelectric crystals at various depths in the target were also used to determine the TOA of the loading shock wave. The TOA at each instrument location was plotted versus its depth in the target. The inverse slope of the best linear fit through the data was taken as the propagation velocity of the loading wave. Perfectly normal impact of the projectile onto the target was assumed in this analysis. Also, a single value for the loading-wave propagation was determined, when, in fact, the propagation velocity may vary at different stress levels.

Presented in Figures 3-4 through 3-6 are TOA vs. depth plots for Tests 23, 24, and 25, respectively. Time-of-arrival measurements at the surface of the target were successful only on Test 24 (due to the failure of the self-shorting pins on Tests 23 and 25), and are included with the data presented in Figure 3-5. The derived propagation velocities from the test data were 910, 815 and 810 m/sec, respectively. These values are more than two times higher than typical values for granular soils (see White and Byrne, 1994).

While the velocity from the first test is about 12 percent higher than that of the latter two tests, the repeatability is good. The consistency of the derived propagation velocity demonstrates the potential use of the gas gun for gage validation studies by providing a repeatable environment in which to test instruments.

3.2.2 Propagation Velocity of Relief Wave.

A relief wave (or unloading wave) was generated in each target by the interaction of the initial loading shock wave with the free surface at the bottom of the container (and the sides as

well). This is a result of the initial compressive wave traveling through the target being reflected from the free surface (bottom surface or sides) as a tensile, or relief wave. The superposition of the tensile reflection and the still-impinging compressive wave resulted in a decrease in stress and an increase in particle velocity.

A graphical method was used to determine the propagation velocity of the relief wave for two of the tests in F-75 Ottawa sand. This method depended on witnessing the TOA of the relief wave on individual gage records. The following assumptions were made in this analysis:

- the displacements of a stress gage and an accelerometer canister at the same depth were identical
- the propagation velocity of the relief wave was constant
- perfectly normal impact occurred onto the target.

A schematic of the location of stress and velocity gages fielded in a target in their original position and at a later time is presented in Figure 3-7. Representative stress and velocity records from the 152-mm and 305-mm depths are shown in Figure 3-8. The TOA of the loading wave and relief wave at each gage location is noted in the figure. The amount that an accelerometer canister displaced between the initial TOA and the TOA of the relief wave was measured from the double-integrated acceleration record. This displacement was added to the original gage position to determine the location of the gage at the TOA of the relief wave. This procedure was followed for instruments at each depth in the target. As mentioned previously, TOA crystals were located at several depths in the target to monitor the TOA of the loading shock wave. One such measurement was made at the bottom of the target container, where the loading wave becomes a relief wave, thus providing an additional data point for consideration in determining the relief wave velocity.

Figure 3-4 (Test 23) is repeated in Figure 3-9, with additional data representing the location of various gages at the TOA of the relief wave. The two clusters of relief-wave TOA data

represent gages at the two instrumented depths, 152 mm and 305 mm. As was done when determining the propagation velocity of the loading wave, the inverse slope of the linear fit through the data was taken as the velocity of the relief wave. A propagation value of 1,315 m/sec was determined for the relief wave in Test 23. Presented in Figure 3-10 is a similar plot for Test 24. Only the TOA measurement at the bottom of the target and the gages at the 305-mm depth were used to determine the relief wave speed because of the failure of the acceleration measurements at the 152-mm depth prior to TOA of the relief wave. This prohibited a measure of the displacement of instruments at that depth. The linear fit through the data indicates a relief-wave velocity of 1,305 m/sec, which is essentially identical to that determined for Test 23. Test 25 was not analyzed because of failures or discrepancies in the acceleration measurements at both the 152-mm and 305-mm depths.

Theoretically, the two lines in Figures 3-9 and 3-10 representing the best fit through the loading TOA and relief TOA should meet at the bottom of the target, i.e., at the 0.61-m depth, represented by the dashed line in the figures. An error in any one of the assumptions or errors in placing the gages in the target could result in the slight discrepancy seen in the figures.

3.3 MEASURED STRESS IN THE TARGETS.

Presented in Figures 3-11, 3-12, and 3-13 are stress wave forms from Tests 23, 24, and 25, respectively. Various types of stress transducers were positioned at two depths in each target (see Figure 2-6). Reasonably good agreement in the overall wave forms is seen. Some of the apparent disagreement in peaks is due to the inertial response of a gage. A gage in the sand target has an inertial resistance to acceleration, which causes the stagnation of sand against the gage face. Until the gage achieves equilibrium with the free-field velocity, the gage is exposed to an inertial (or stagnation) stress significantly

higher than the free-field stress. This is a result of the impedance mismatch between the gage and the surrounding media. The data from the tests are considered quite good. More information on the response of the types of stress gages used in these experiments may be found in Rocco et al. (1994); Veyera and Rinehart (1986); and Rinehart (1993).

Presented in Figure 3-14 are comparisons of stress measurements from identical gage types and locations fielded in Tests 23, 24, and 25. The repeatability of the environment from test to test may be seen more readily from comparisons of individual gage types, because the inertial and impedance mismatch effects would be identical for each instrument. The consistency of the data from test to test, for a given gage type, is extremely good. This indicates the repeatability of the stress environment generated in identical tests.

3.4 MEASURED PARTICLE VELOCITY IN THE TARGETS.

Presented in Figures 3-15, 3-16, and 3-17 are velocity wave forms from Tests 23, 24, and 25, respectively. Noted in each figure is the response of an internal shock mount used in the Wedge canister. This low frequency ringing is typical for this instrument. The responses of the other accelerometers on each test, where they survived, are considered good.

Presented in Figure 3-18 are comparisons of velocity measurements from identical gage types and locations fielded in Tests 23, 24, and 25. The consistency of the measured data from these tests shows the repeatability of the ground shock generated by the gun from test to test.

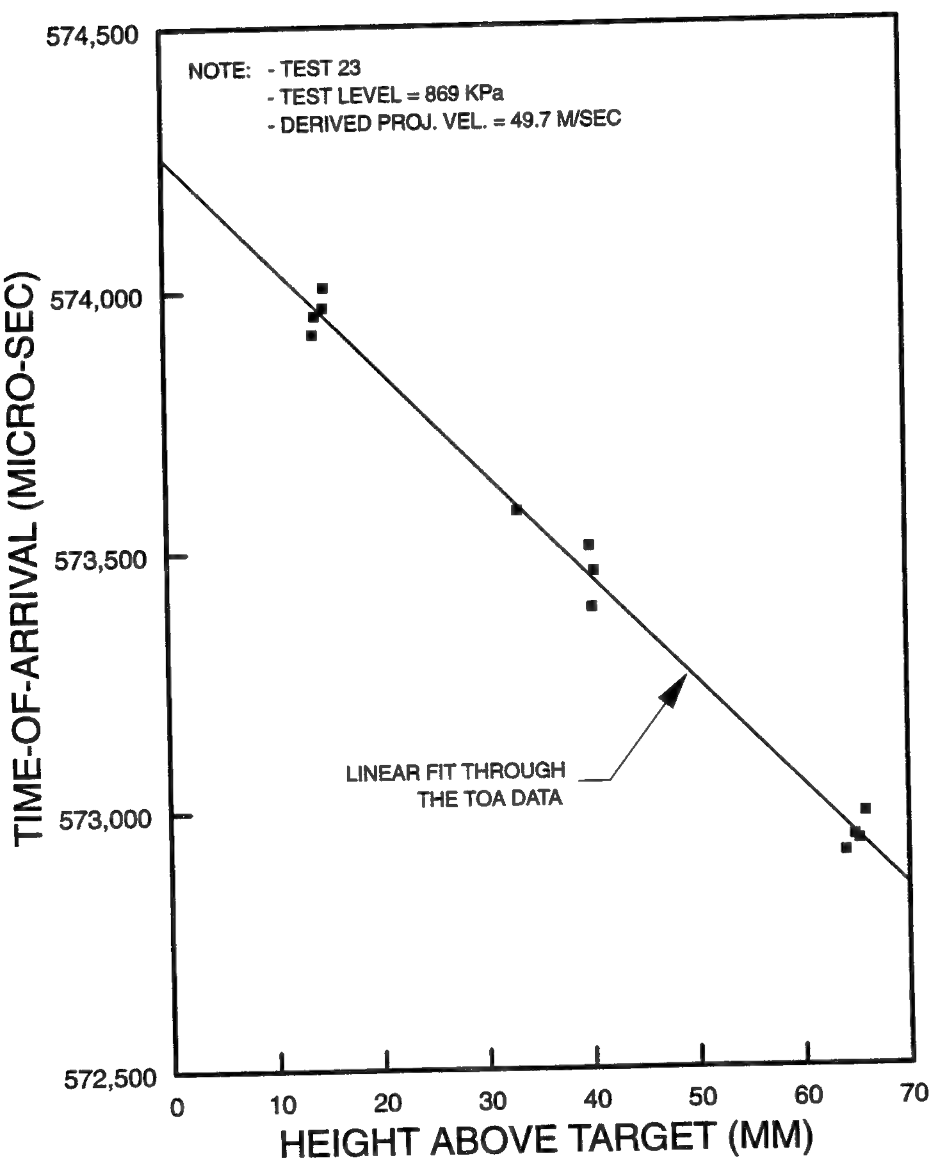


Figure 3-1. Plot of TOA vs. pin height for Test 23. The inverse slope of the best linear fit is the impact velocity (49.7 m/sec).

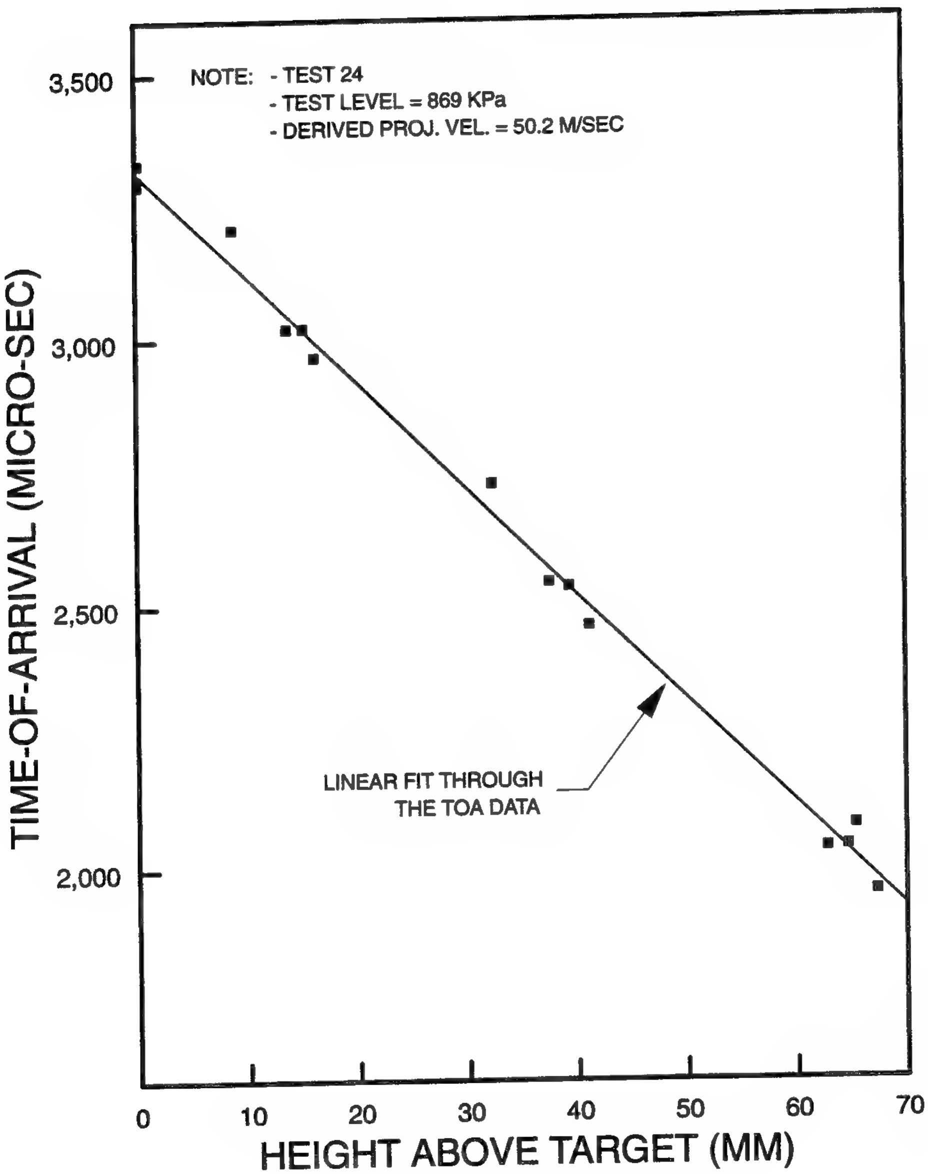


Figure 3-2. Plot of TOA vs. pin height for Test 24. The inverse slope of the best linear fit is the impact velocity (50.2 m/sec).

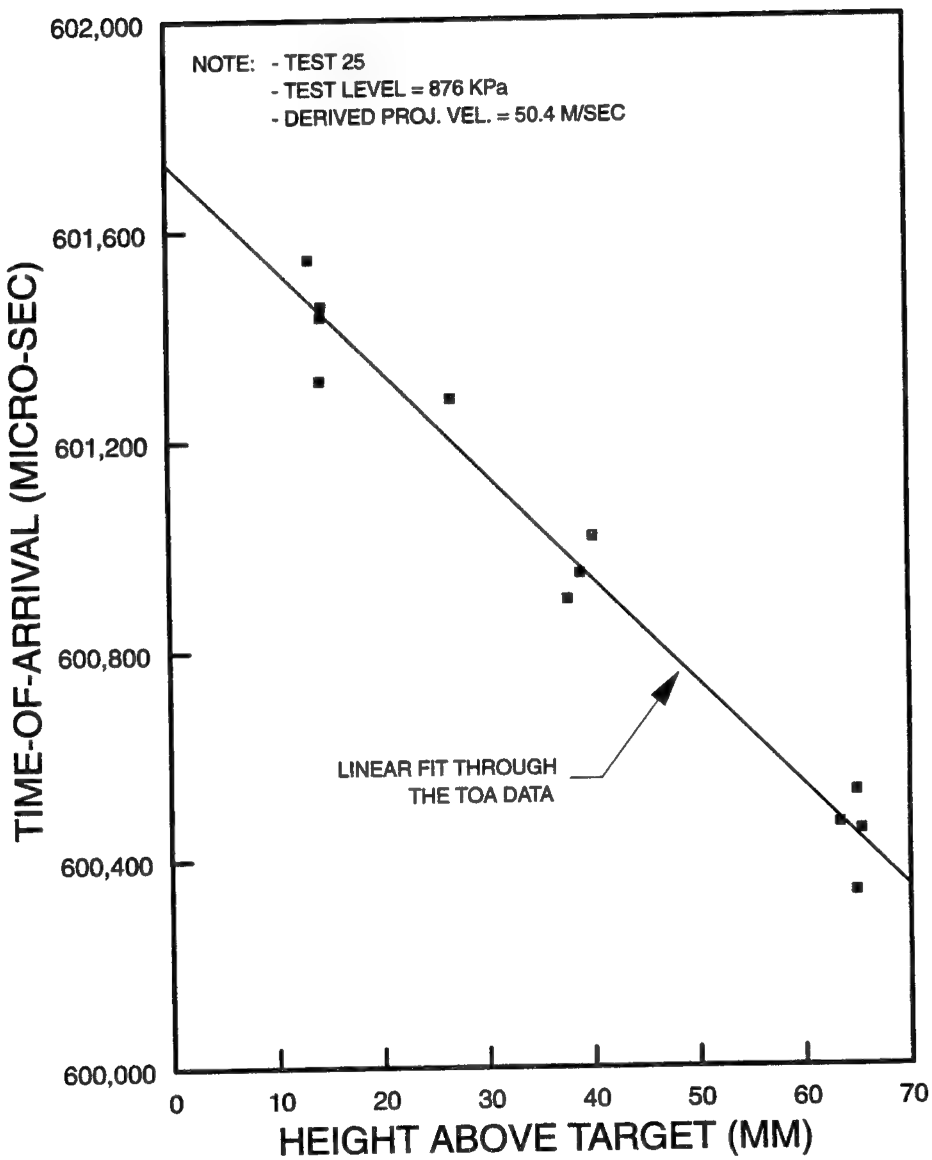


Figure 3-3. Plot of TOA vs. pin height for Test 25. The inverse slope of the best linear fit is the impact velocity (50.4 m/sec).

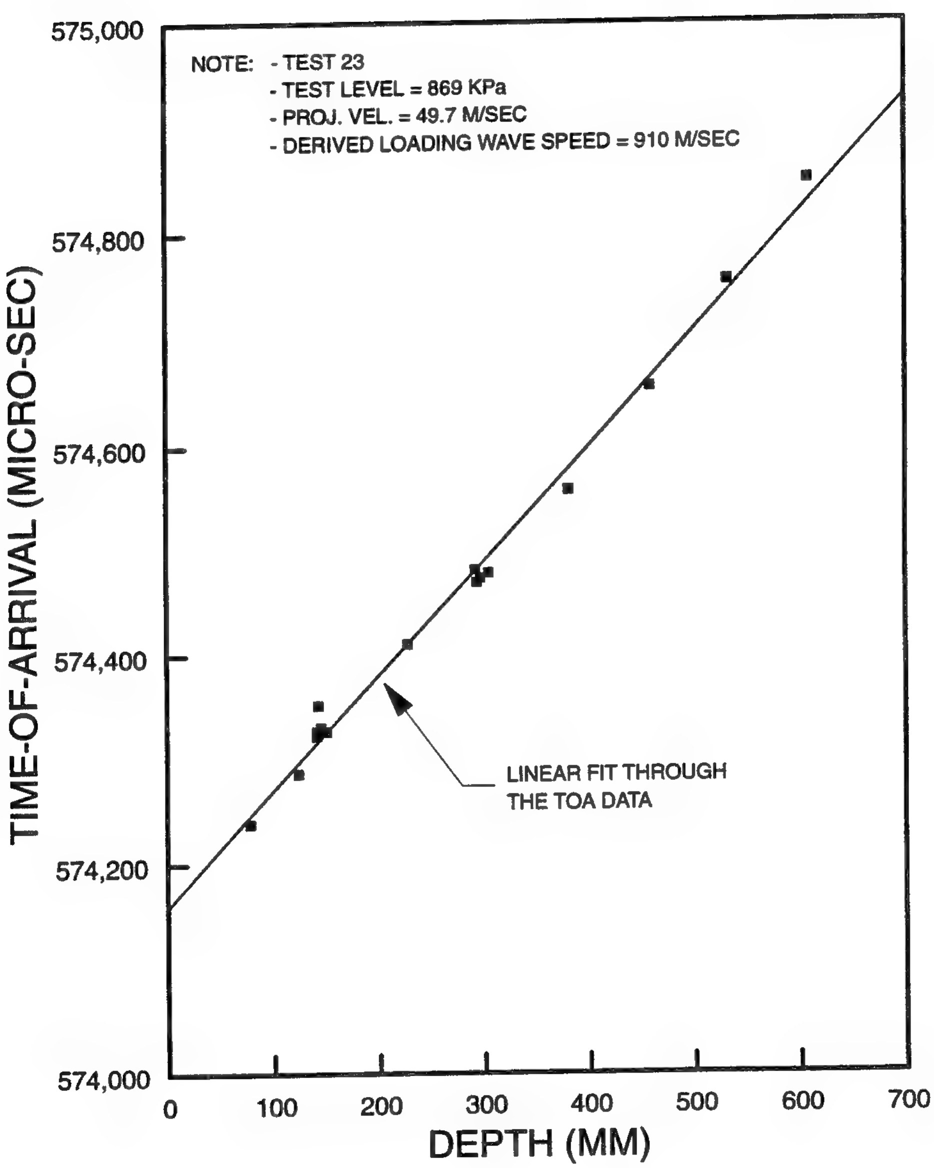


Figure 3-4. Time-of-arrival vs. depth, for Test 23, used to determine the propagation velocity of the loading shock wave.

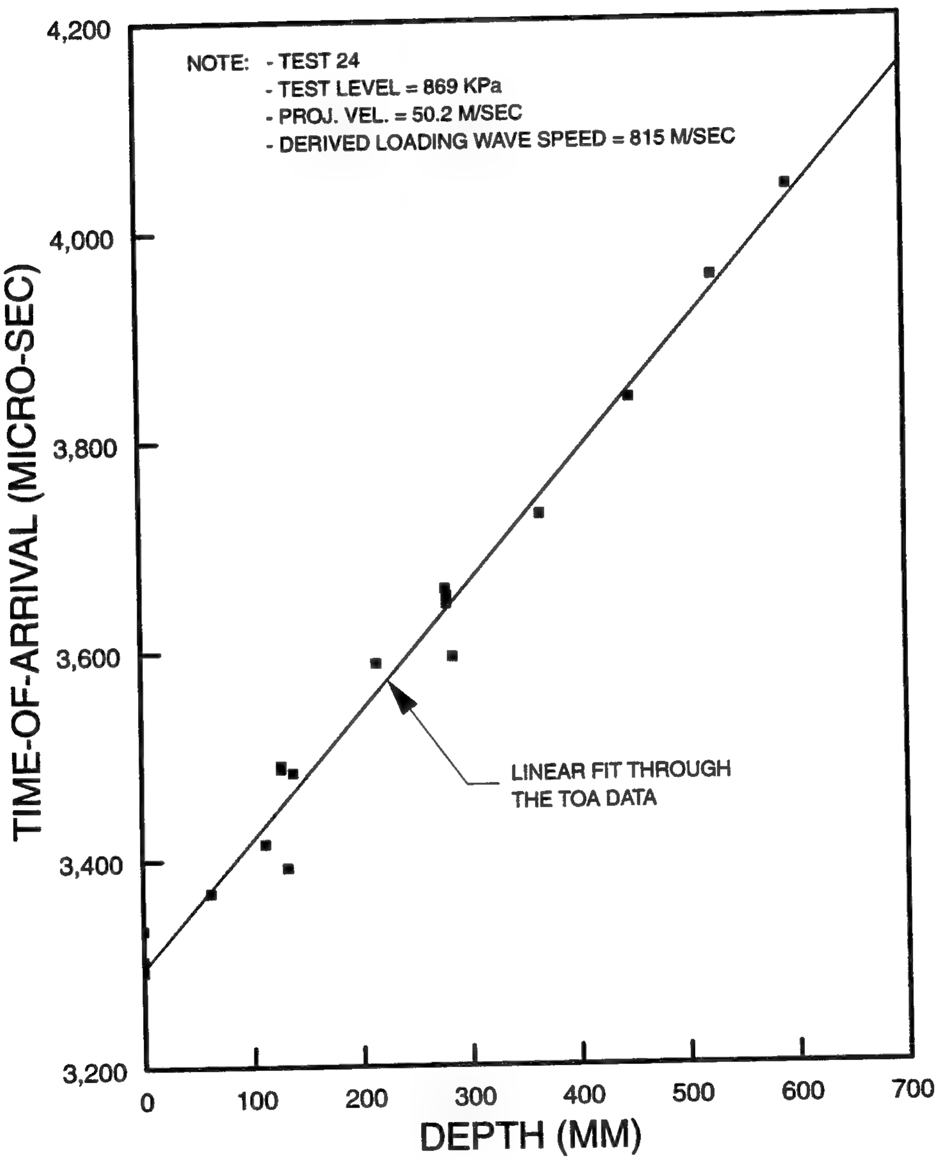


Figure 3-5. Time-of-arrival vs. depth, for Test 24, used to determine the propagation velocity of the loading shock wave.

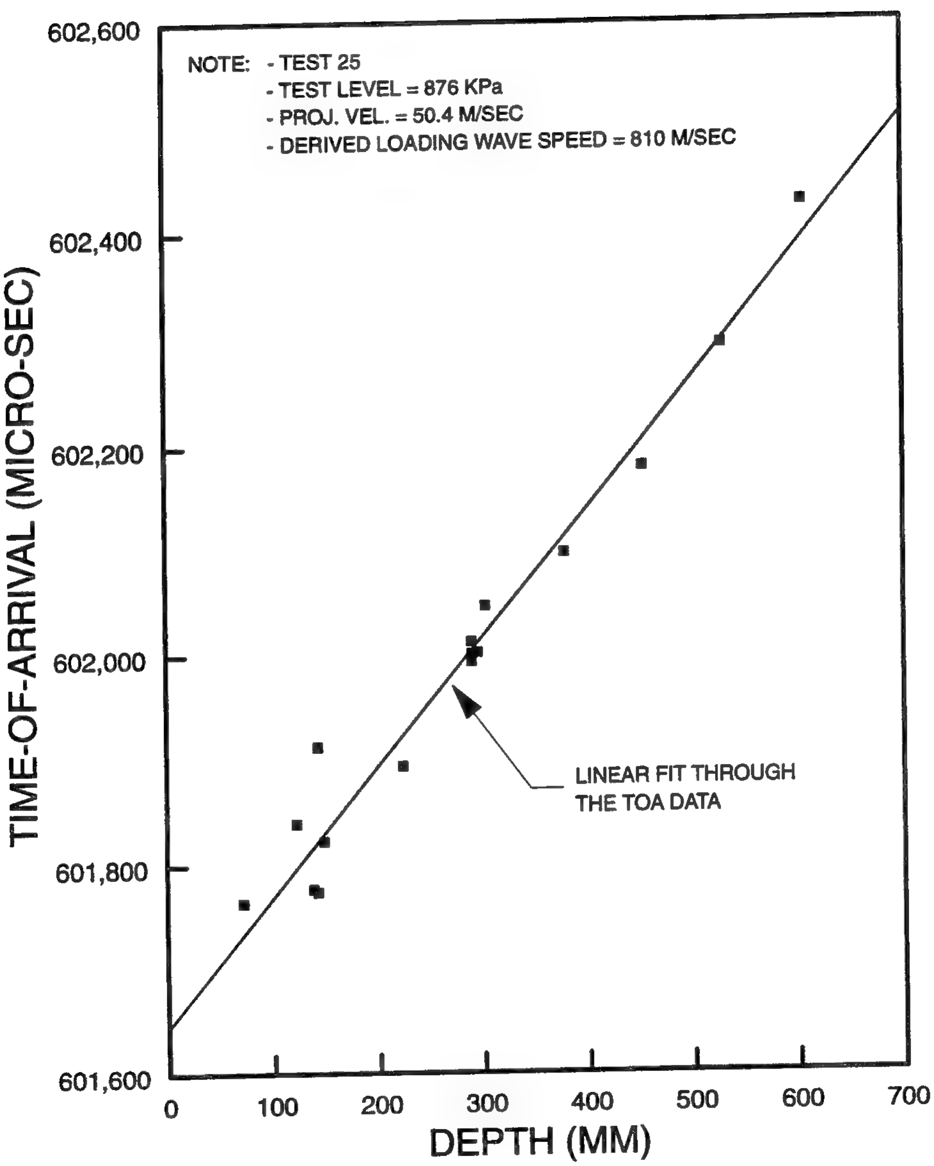


Figure 3-6. Time-of-arrival vs. depth, for Test 25, used to determine the propagation velocity of the loading shock wave.

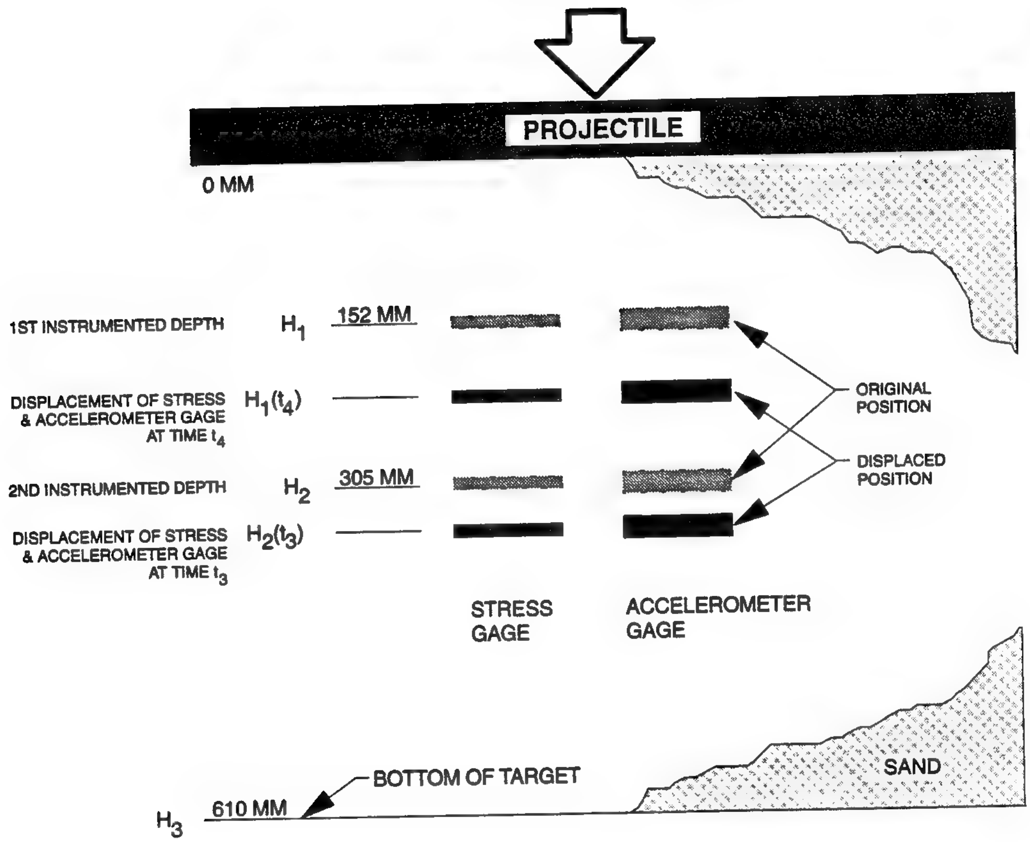


Figure 3-7. Schematic of canister positions at TOA of the loading and relief waves.

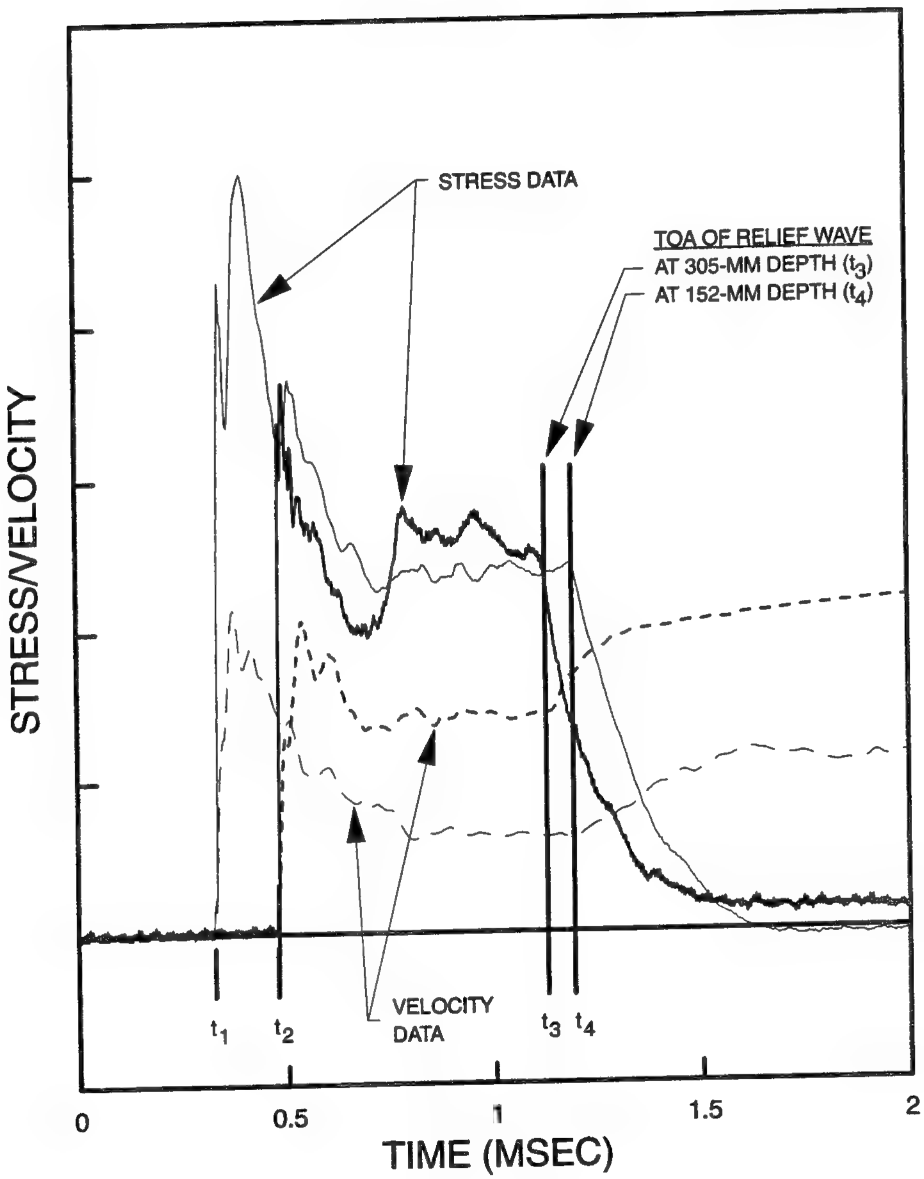


Figure 3-8. Stress and velocity measurements at the two instrumented depths, indicating the TOA of the loading (t_1 and t_2) and relief (t_3 and t_4) waves.

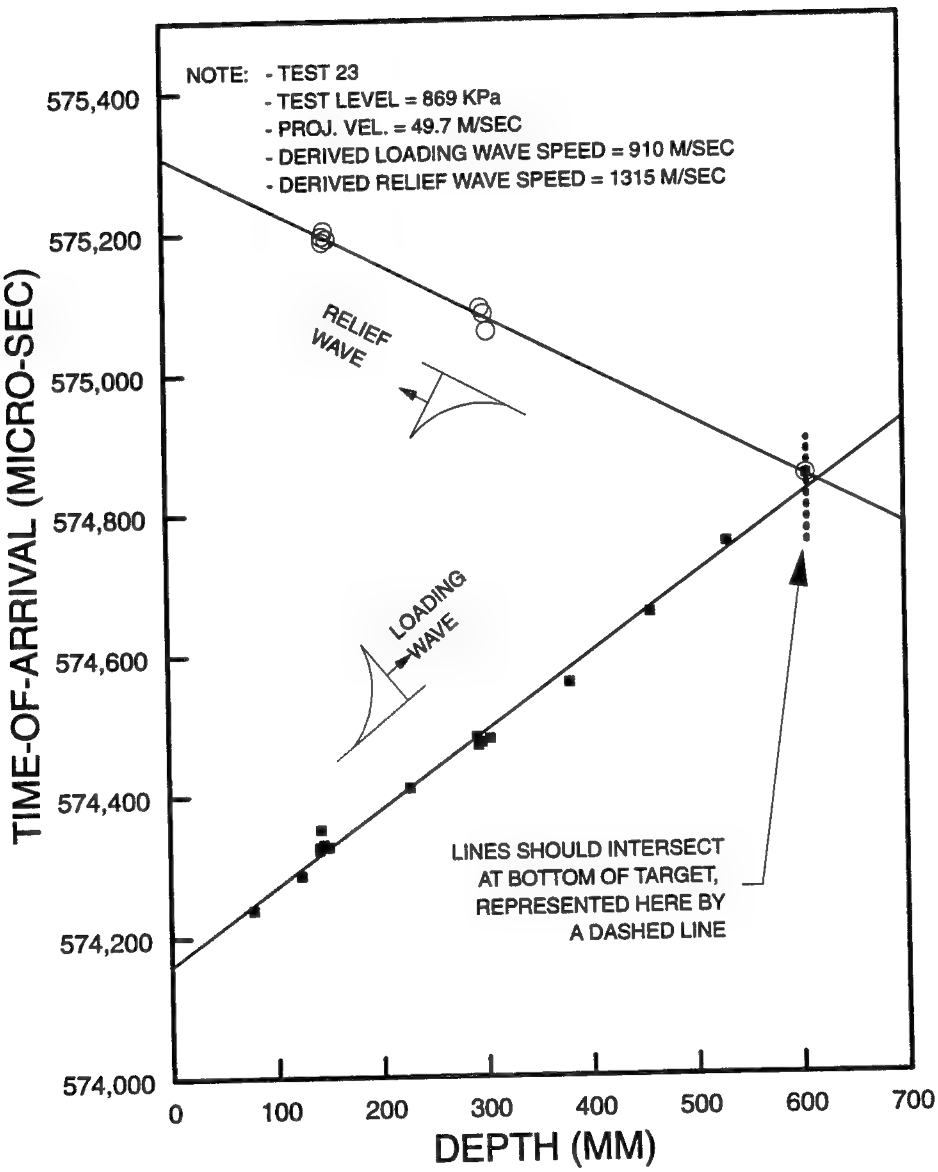


Figure 3-9. Graphical determination of the relief wave speed for Test 23.

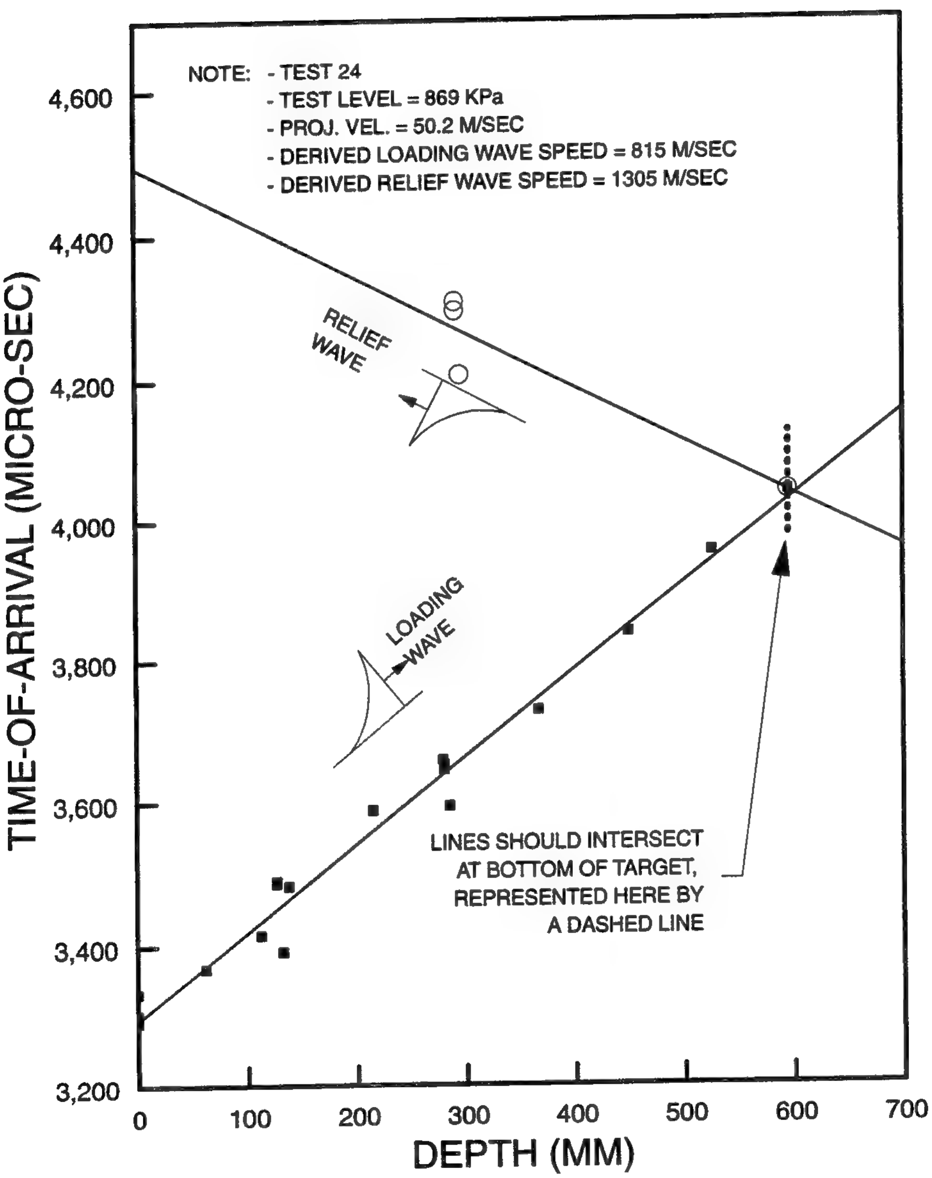


Figure 3-10. Graphical determination of the relief wave speed for Test 24.

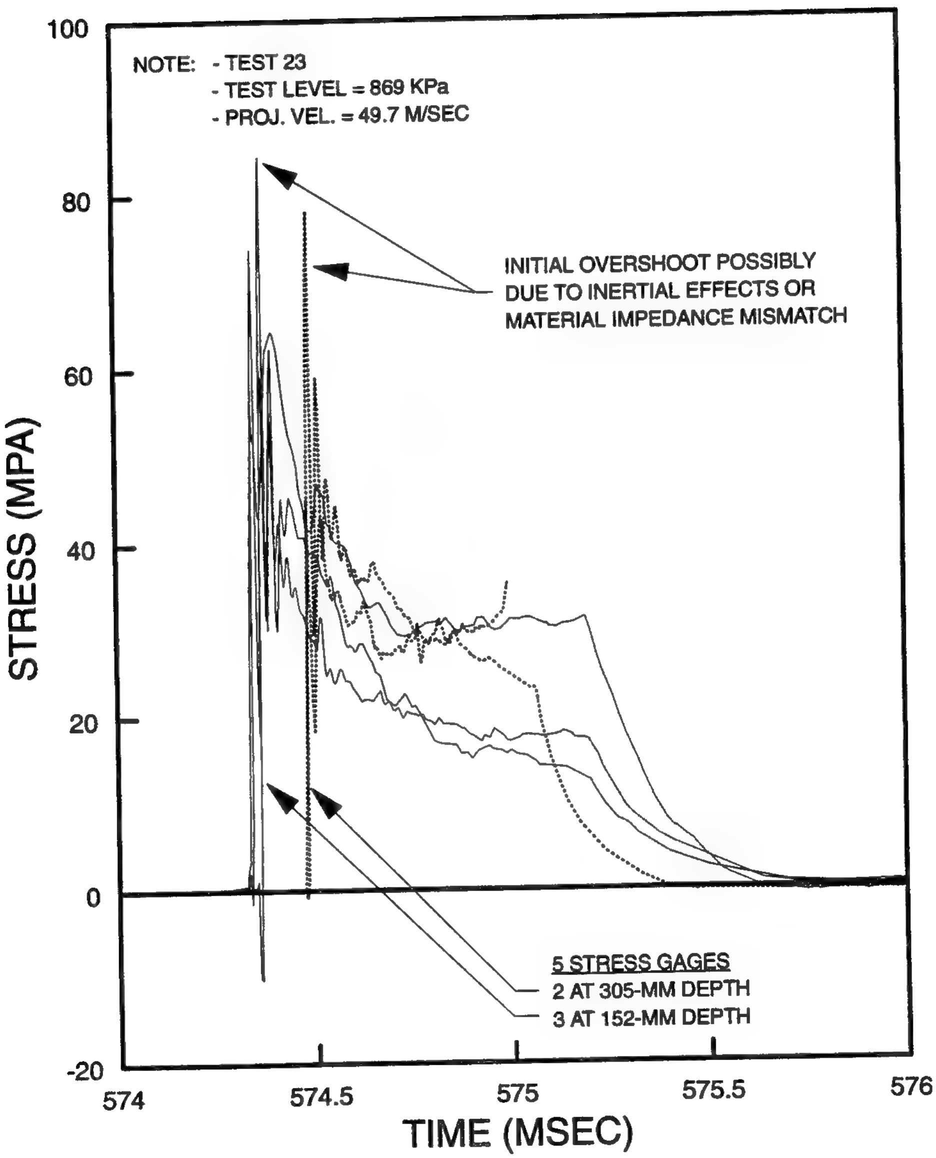


Figure 3-11. Stress measurements from Test 23.

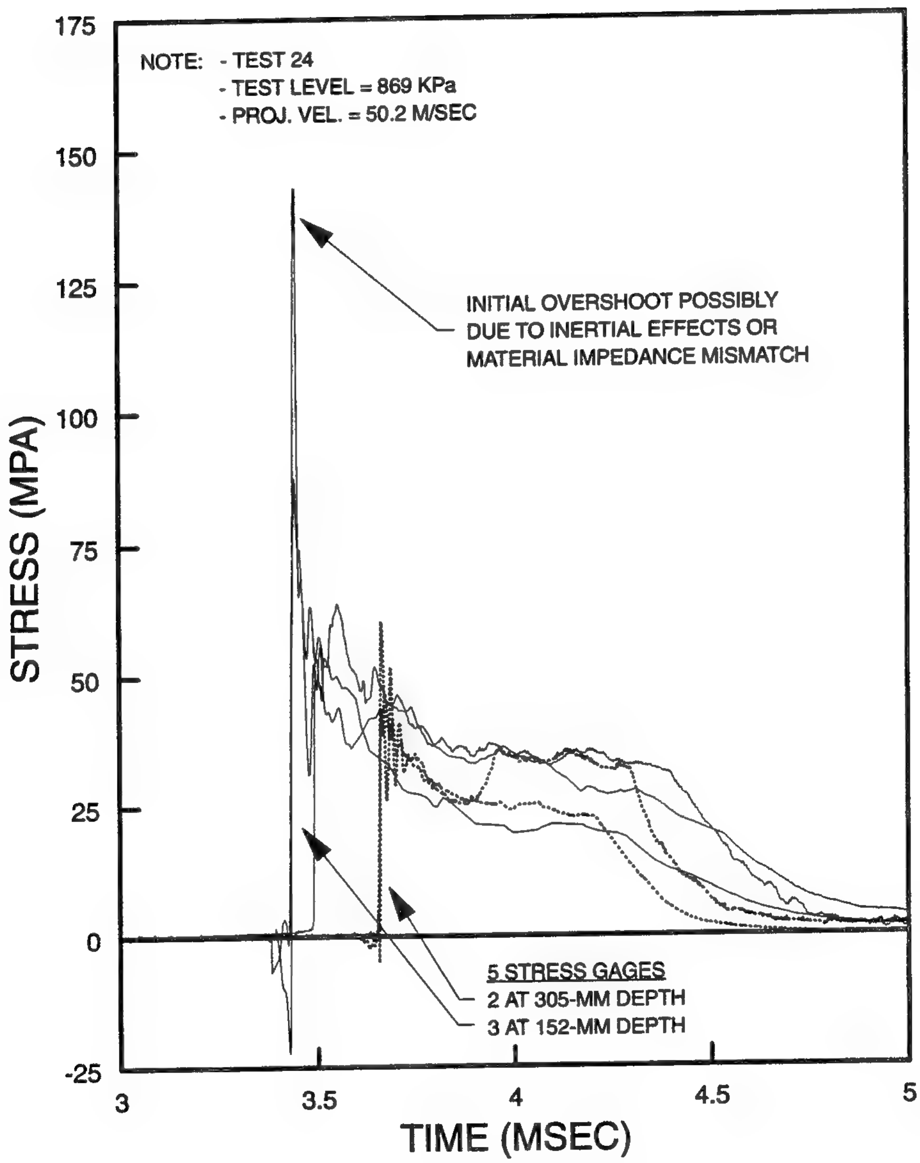


Figure 3-12. Stress measurements from Test 24.

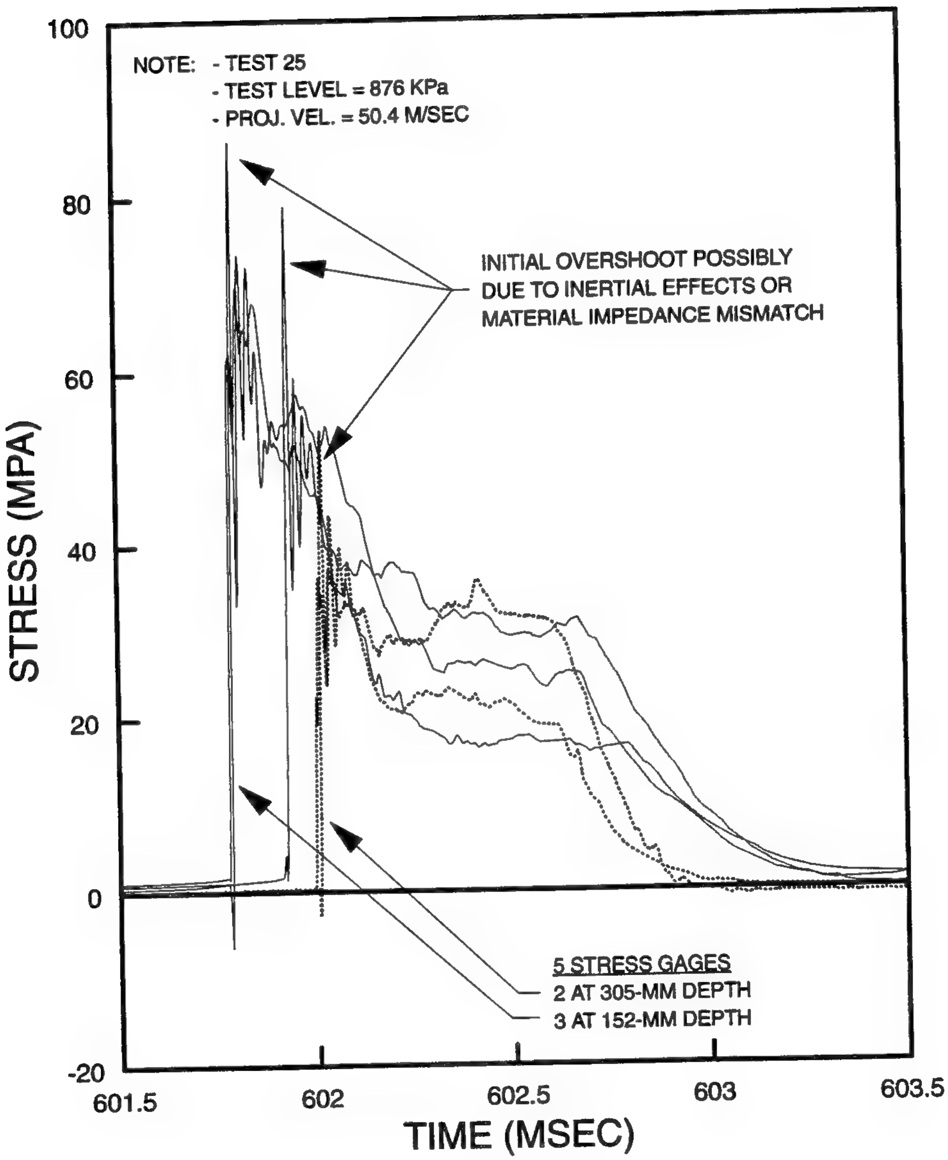


Figure 3-13. Stress measurements from Test 25.

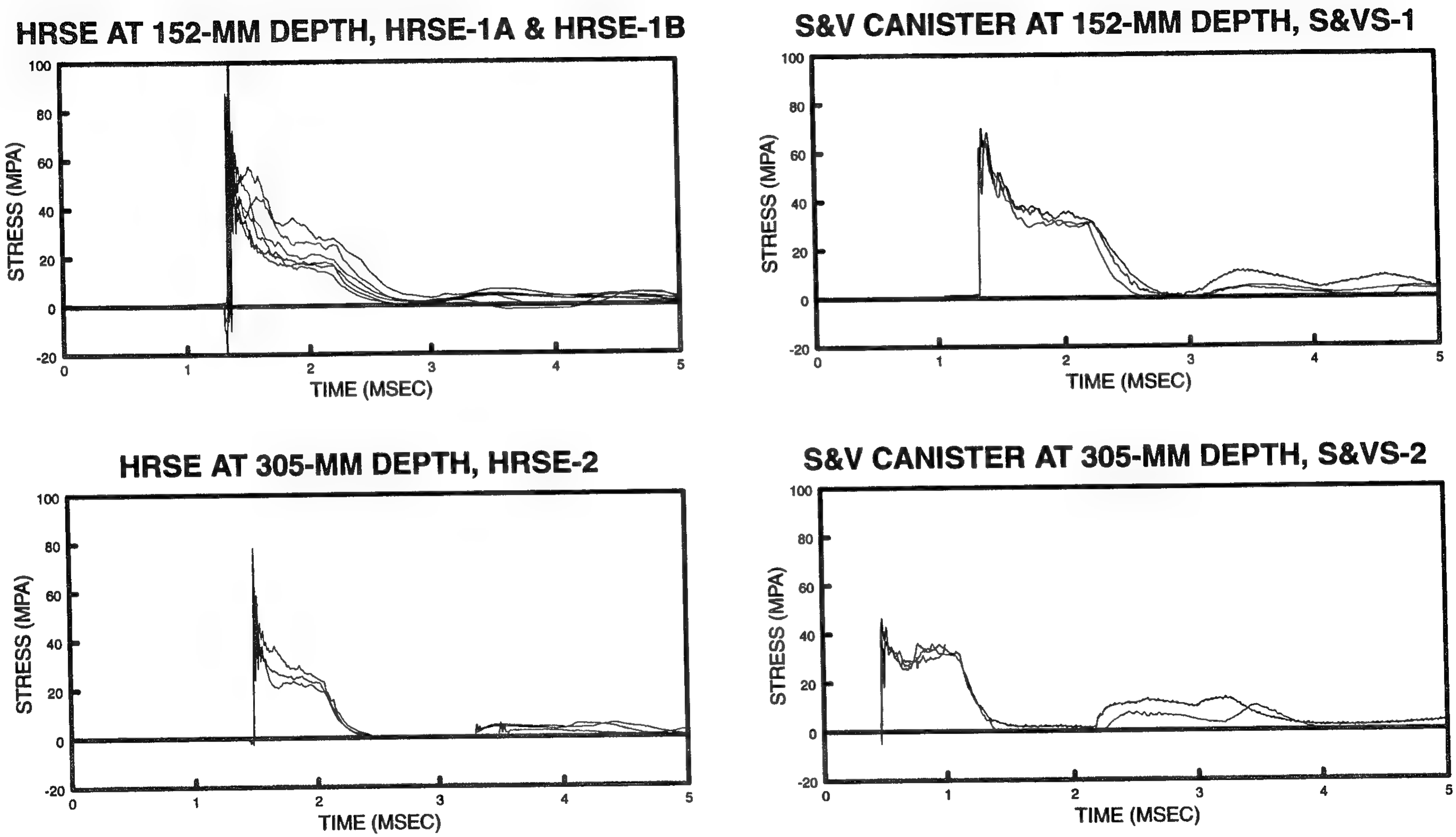


Figure 3-14. Comparison of stress measurements, from similar gage types and locations, for the three identical tests.

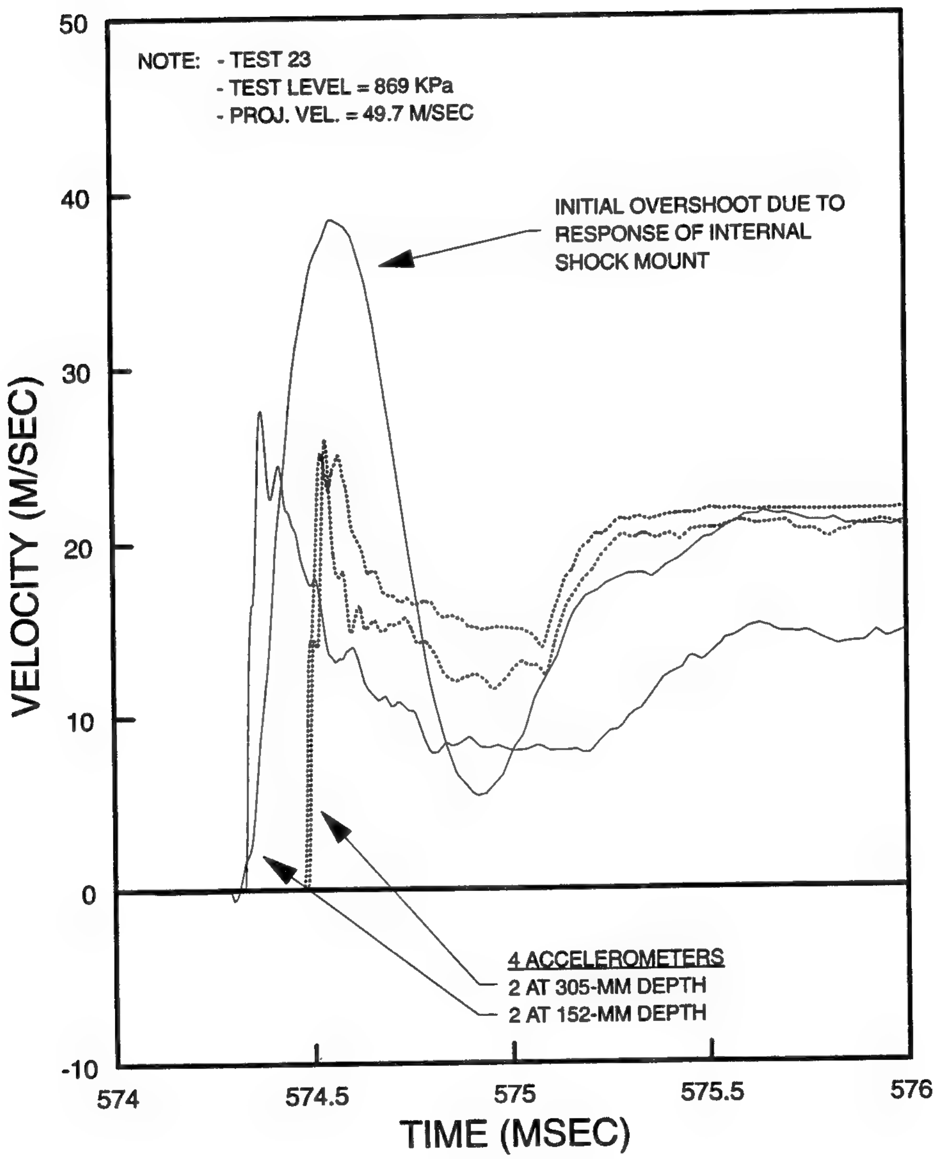


Figure 3-15. Velocity measurements from Test 23.

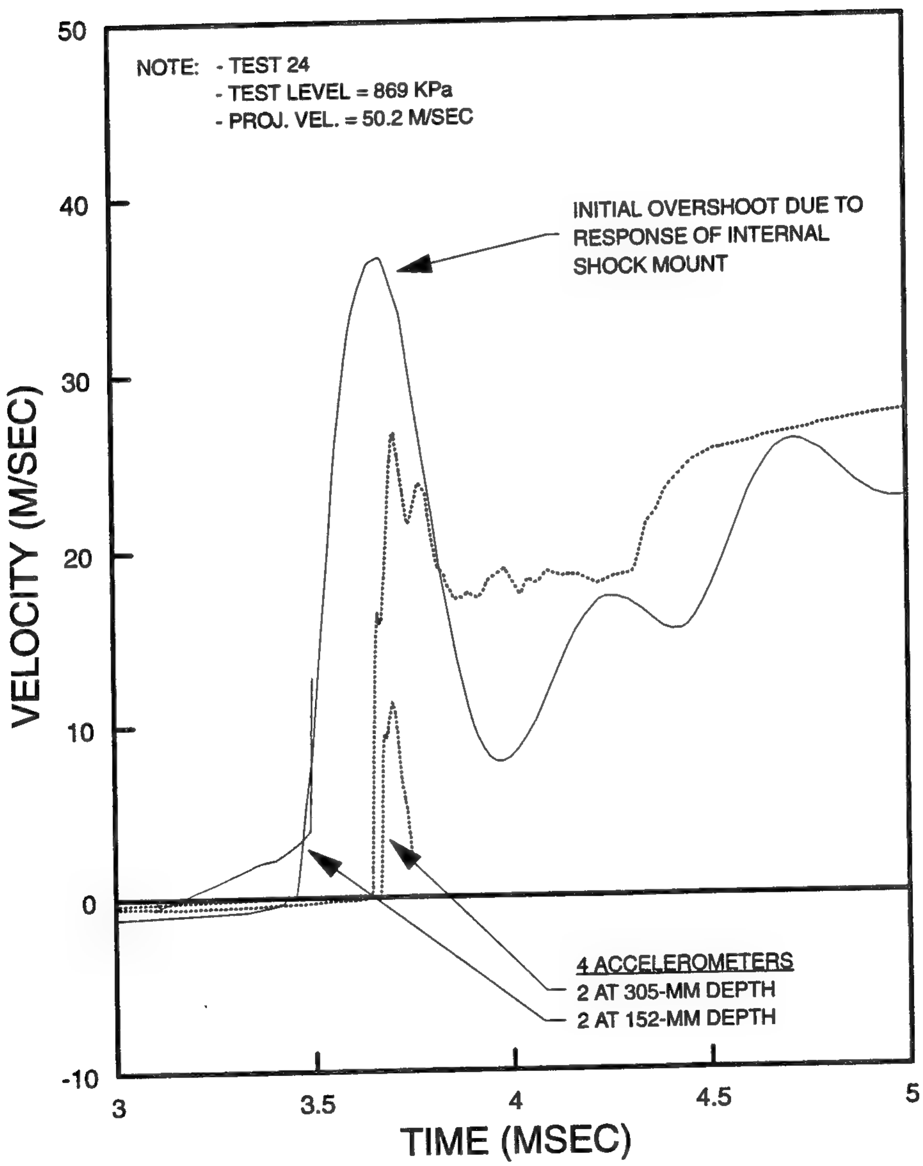


Figure 3-16. Velocity measurements from Test 24.

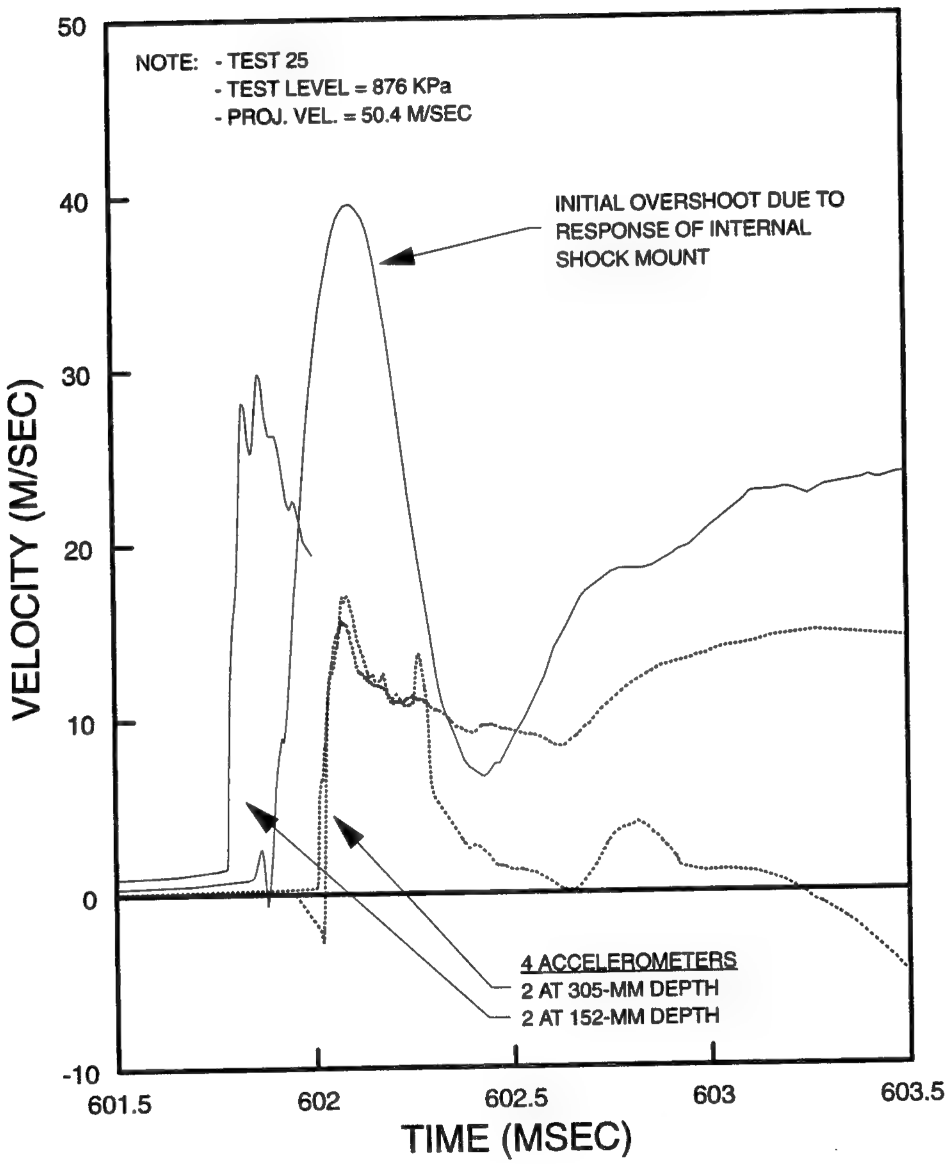


Figure 3-17. Velocity measurements from Test 25.

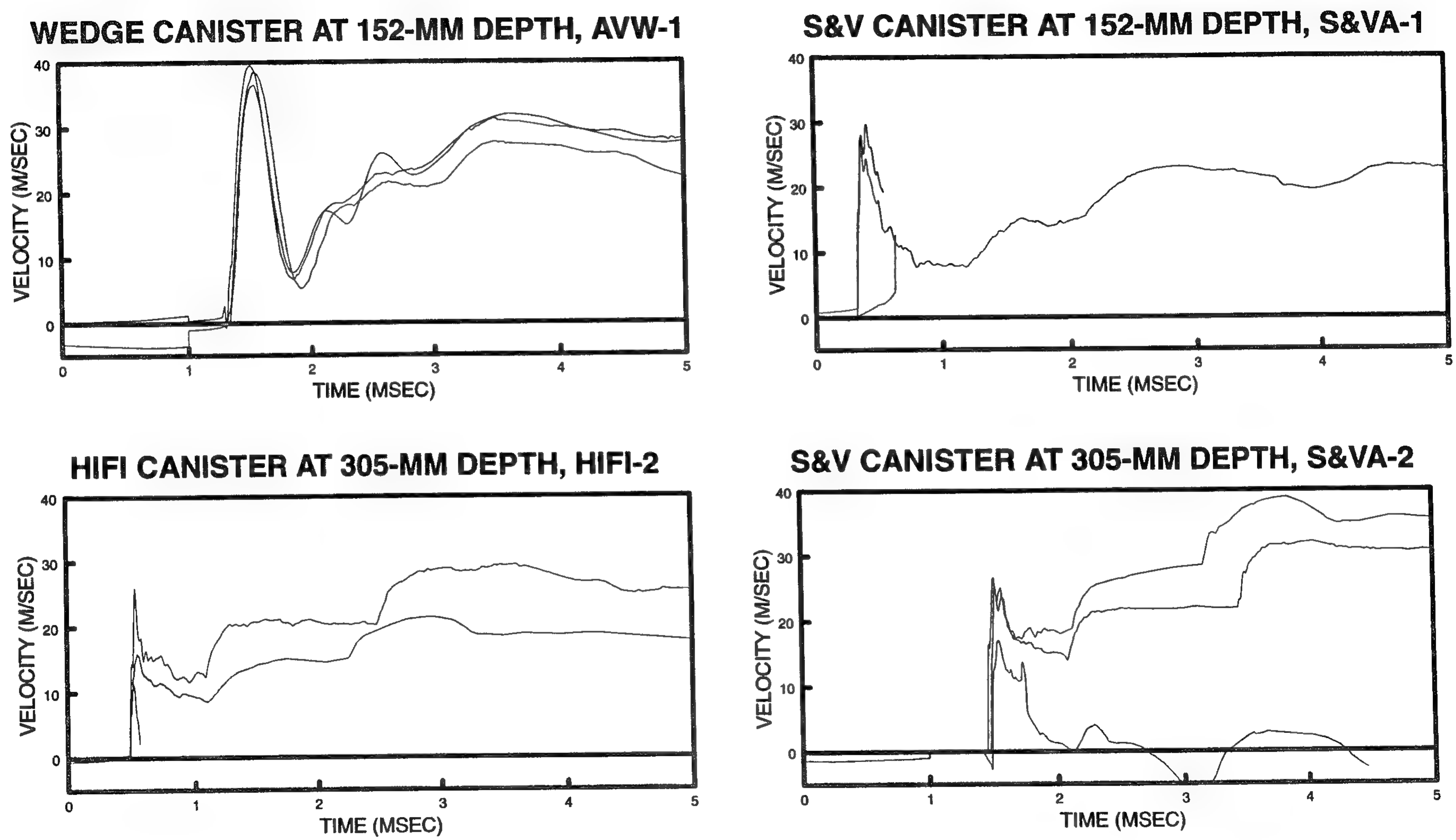


Figure 3-18. Comparison of velocity measurements, from similar gage types and locations, for the three identical tests.

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS.

A material was selected and a construction method was developed for use in preparing standardized granular targets for the DNA/WES Ground Motion Test Facility. These consisted of a nearly dry, poorly-graded material (F-75 Ottawa sand) and a vibratory placement method. This combination produced targets with uniform density profiles throughout their depth. Gage locations were not altered when using the vibratory placement method. Two days were required to build a target containing 19 instruments.

Results from both diagnostic and active instrumentation in three identical tests with the gas gun indicated that essentially identical ground shock environments were generated on each test. Hence, the material used as the target medium, the procedures employed in target construction, and the ability of the gun to deliver the projectile at the same velocity, combined to produce known and repeatable stress and motion fields in the targets. The predictability and repeatability of these environments make the gas gun a unique tool for conducting gage validation experiments on developmental instrumentation.

4.2 RECOMMENDATIONS.

The DNA/WES Ground Motion Test Facility provides a mechanism to conduct many interesting types of tests. These include tests on new (and existing) instrumentation that evaluate gage response in a particular geologic material. The only target medium investigated here was a granular material. There are a myriad of other materials of interest that could be tested, e.g., saturated soils, clays, limestone, granite, marble, and various mixtures of concrete.

The 4-ft gas gun also provides a means for obtaining ground motion data for ground shock transmission in jointed material

under tightly-controlled conditions. Tests could be conducted to investigate the relative effect of variations in joint properties (roughness, saturation, continuity, and orientation) on ground shock transmission, as well as the material's constitutive behavior. The data would provide a database for material modelers to develop "smeared" (or macroscopic) material models for a discontinuous material. These material models could be used to help determine the suitability or capability of continuum codes to predict the responses of a jointed material.

SECTION 5

REFERENCES

Arulmoli, K. and Taylor, L. R. (1988). "Large-Scale Laboratory Stress Chamber System for Simulation of In Situ Soil Testing." Contract Report for USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

Dynasen, Inc. (1993). "Shock Pressure Sensors and Impact Test Facility." Dynasen, Inc., Goleta, CA 93117.

Gilbert, P. A. (1988). "Computer Controlled Microwave Oven System for Rapid Water Content Determination." WES Technical Report GL-88-21, USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

Gilbert, P. A. (1990). "Computer-Controlled Microwave Drying of Potentially Difficult Organic and Inorganic Soils." WES Technical Report GL-90-26, USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

Henry, F. P. (1991). "General Plastics Last-A-Foam® FR-3700 for Crash and Fire Protection of Nuclear Material Shipping Containers." General Plastics Manufacturing Co., Tacoma, WA 98409

Ingram, J. K. (1968). "Development of a Free-Field Soil Stress Gage for Static and Dynamic Measurements." WES Technical Report 1-814, USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

Joachim, C. E. (1985). Design calculations and sketches on the 12-in. diameter vertical gas gun, unpublished, USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

Landry, M. (1994). "High Bandwidth Fiber Optic Accelerometer." Proceedings of the Defense Nuclear Agency Instrumentation for Nuclear Weapons Effects Testing (INWET) Conference, 2-5 November 1993. Defense Nuclear Agency, Alexandria, VA 22310-3398.

Ohrt, A. P. (1988a). Gamma law gas corrections to initial theoretical treatment of gas gun design with water reaction mass, unpublished, USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

Ohrt, A. P. (1988b). Design caluclations and sketches for the 4-ft diameter vertical gas gun, unpublished, USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

Phillips, B. R. (1991). "Backfilling of Test Container for Gas Gun Tests - Report of Telephone Conversation." USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

Rinehart E. J. (1993). "The Effect of Geometry on Stress Measurements." Proceedings of the 64th Shock and Vibration Symposium, Volume 2, 26-28 October 1993. Naval Surface Warfare Center, Silver Spring, MD.

Rocco, J. R., Rinehart, E. J., Welch, C. R., White, H. G., and Thomsen J. M. (1994). "Response of WES Column-Based Stress Gages to Kilobar Level Shocks in Dry Sand and Saturated Limestone." Proceedings of the Defense Nuclear Agency Instrumentation for Nuclear Weapons Effects Testing (INWET) Conference, 2-5 November 1993. Defense Nuclear Agency, Alexandria, VA 22310-3398.

Veyera, G. E. and Rinehart, E. J. (1986). "Inertial Effects on Field Gage Records." Technical Report CRTA-TR-3810-2. California Research and Technology, Inc., Albuquerque, NM.

Welch, C. R. (1983). Initial theoretical treatment of gas gun design with water reaction mass, unpublished, USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

Welch, C. R. (Editor) (1986). "Silo Test Program (STP) 3.5A Event, Volume 1 - The Test Environment." WES Technical Report SL-84-11, USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

Welch, C. R., and White H. G. (1987). "Shock-Isolated Accelerometer Systems For Measuring Velocities In High-G Environments." Shock and Vibration Bulletin 57, The Shock and Vibration Information Center, Naval Research Laboratory, Washington, DC.

Welch, C. R., White, H. G., and King, P. K. (1992). "HydroPlus TID Program Work Accomplished To Date - 18 September 1992." USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

Welch, C. R., White, H. G., Fuller, B. D., and Rickman D. D. (1994). "WES Third-Generation, High-Fidelity, Particle Velocity Gage." Proceedings of the Defense Nuclear Agency Instrumentation for Nuclear Weapons Effects Testing (INWET) Conference, 2-5 November 1993. Defense Nuclear Agency, Alexandria, VA 22310-3398.

Welch, C. R. (1993). "Column-Based Stress Gage." Corps of Engineers Patent Application COE 307, United States Patent and Trademark Office, Washington, DC 20231.

White, H. G. (1988). Design calculations and sketches on the quick-release trigger mechanism for the 12-in. diameter vertical gas gun, unpublished, USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

White, H. G. (1989). "Development Of A High-Range Particle-Velocity Gage." WES Technical Report SL-89-3, USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

White, H. G. (1990a). Design calculations and sketches on the 4-ft diameter projectile, unpublished, USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

White, H. G. (1990b). Design calculations and sketches on the quick-release trigger mechanism for the 4-ft diameter vertical gas gun, unpublished, USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

White, H. G. (1990c). "Hydrostatic and Vacuum Testing of the WES 4-ft Diameter Vertical Gas Gun." Letter report to the Defense Nuclear Agency. USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

White, H. G., Ohrt, A. P., Welch, C. R., and Joachim, C. E. (1991). "Design and Testing Experiences with the WES 12-in. and 4-ft Diameter Vertical Gas Guns." Proceedings of the Defense Nuclear Agency Instrumentation for Nuclear Weapons Effects Testing (INWET) Conference, 16-19 April 1991. Volume 1-General Session and Sessions I and II, DASIAC-TR-91-001-V1, Defense Nuclear Agency, Alexandria, VA 22310-3398.

White, H. G. (1993a). "Performance Tests with the WES 4-ft-Diameter Vertical Gas Gun." DNA-TR-93-16, Defense Nuclear Agency, Alexandria, VA 22310-3398.

White, H. G. (1993b). "Test Plan for Test 23 with the WES 4-ft Diameter Vertical Gas Gun." USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

White, H. G. (1993c). "Test Plan for Test 24 with the WES 4-ft Diameter Vertical Gas Gun." USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

White, H. G. (1993d). "Test Plan for Test 25 with the WES 4-ft Diameter Vertical Gas Gun." USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

White, H. G. (1994a). "Development of a Large-Diameter Gas Gun for Studies of Gage Validation and Dynamic Material Properties." WES Technical Report SL-94-2, USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

White, H. G. (1994b). "DNA/WES Ground Motion Test Facility - Initial Tests Against Concrete." In publication, USAE Waterways Experiment Station, Vicksburg, MS 39180-6199.

White, H. G., Ohrt, A. P., and Welch, C. R. (1994). "Gas Gun and Quick-Release Mechanism for Large Loads." U. S. Patent No. 5,311,856. United States Patent and Trademark Office, Washington, DC, 20231.

White, H. G. and Byrne, J. T. (1994). "DNA/WES Ground Motion Test Facility - Results and Analysis of Impact Tests Against Masonry and Socorro Plaster Sand Testbeds." DNA-TR-93-114, Defense Nuclear Agency, Alexandria, VA 22310-3398.

White, H. G., and Welch, C. R. (1994). "Initial Ground Shock Tests in Sand Using the WES 4-ft Diameter Vertical Gas Gun." Proceedings of the Defense Nuclear Agency Instrumentation for Nuclear Weapons Effects Testing (INWET) Conference, 2-5 November 1993. Defense Nuclear Agency, Alexandria, VA 22310-3398.

DISTRIBUTION LIST

DNA-TR-94-145

DEPARTMENT OF DEFENSE

ASSISTANT TO THE SECRETARY OF DEFENSE
ATTN: EXECUTIVE ASSISTANT

DEFENSE INTELLIGENCE AGENCY
ATTN: PGI-4

DEFENSE NUCLEAR AGENCY
2 CY ATTN: IMTS
ATTN: SPSD D PYLE
ATTN: SPSD P SENSENY
ATTN: SPWE
ATTN: SPWE E TREMBA
ATTN: SPWE K PETERSEN
ATTN: TDTR

DEFENSE TECHNICAL INFORMATION CENTER
2 CY ATTN: DTIC/OC

FIELD COMMAND DEFENSE NUCLEAR AGENCY
ATTN: FCTI G S LU
ATTN: FCTO
ATTN: FCTT-T E RINEHART
ATTN: FCTT DR BALADI
ATTN: FCTTS G GOODFELLOW
ATTN: FCTTS P RANDLES

DEPARTMENT OF THE ARMY

U S ARMY COLD REGION RES & ENG LAB
ATTN: CECRL-MAILROOM

U S ARMY ENGR WATERWAYS EXPER STATION
ATTN: C WELCH CEWES-SD-R
5 CY ATTN: CEWES-SD-R HOWARD WHITE
ATTN: RESEARCH LIBRARY

U S ARMY NUCLEAR & CHEMICAL AGENCY
ATTN: MONA-NU DR D BASH

U S ARMY RESEARCH LAB
ATTN: SLCBR-SS-T

DEPARTMENT OF THE NAVY

DAVID TAYLOR RESEARCH CENTER
ATTN: CODE 1770

DEPARTMENT OF THE AIR FORCE

AIR FORCE ARMAMENT LABORATORY
ATTN: A BRINSON
ATTN: D WATTS

AIR UNIVERSITY LIBRARY
ATTN: AUL-LSE

DEPARTMENT OF ENERGY

LAWRENCE LIVERMORE NATIONAL LAB
ATTN: ALLEN KUHL

LOS ALAMOS NATIONAL LABORATORY
ATTN: J OGLE

SANDIA NATIONAL LABORATORIES
ATTN: A CHABAI DEPT-9311
ATTN: TECH LIB 3141

OTHER GOVERNMENT

CENTRAL INTELLIGENCE AGENCY
ATTN: OSWR/NED 5S09 NHB

DEPARTMENT OF THE INTERIOR
ATTN: D RODDY

FEDERAL EMERGENCY MANAGEMENT AGENCY
ATTN: OFC OF CIVIL DEFENSE

DEPARTMENT OF DEFENSE CONTRACTORS

AEROSPACE CORP
ATTN: LIBRARY ACQUISITION

AEROTHERM CORP
ATTN: J SAPERSTEIN

APPLIED RESEARCH ASSOCIATES
ATTN: R FLORY

APPLIED RESEARCH ASSOCIATES, INC
ATTN: J KEEFER
ATTN: N ETHRIDGE

APPLIED RESEARCH ASSOCIATES, INC
ATTN: C J HIGGINS
ATTN: F E SEUSY
ATTN: N BAUM

APPLIED RESEARCH ASSOCIATES, INC
ATTN: J SHINN

APPLIED RESEARCH ASSOCIATES, INC
ATTN: R FRANK

APPLIED RESEARCH ASSOCIATES, INC
ATTN: J L DRAKE

BDM FEDERAL INC
ATTN: E DORCHAK

BOEING TECHNICAL & MANAGEMENT SVCS, INC
ATTN: ROBERT M SCHMIDT

CARPENTER RESEARCH CORP
ATTN: H J CARPENTER

FLUID PHYSICS IND
ATTN: R TRACI

GEO CENTERS. INC
ATTN: B NELSON

IIT RESEARCH INSTITUTE
ATTN: DOCUMENTS LIBRARY

JAYCOR
ATTN: J STUHMILLER

JAYCOR
ATTN: CYRUS P KNOWLES

KAMAN SCIENCES CORP
ATTN: D BRYCE
ATTN: J CHANG

KAMAN SCIENCES CORP
ATTN: DASIAC

KAMAN SCIENCES CORPORATION
ATTN: DASIAC

LOGICON R & D ASSOCIATES
ATTN: C K B LEE
ATTN: D SIMONS
ATTN: LIBRARY

LOGICON R & D ASSOCIATES
ATTN: D CARLSON

LOGICON R & D ASSOCIATES
ATTN: B KILLIAN
ATTN: G GANONG
ATTN: J WALTON

MAXWELL LABORATORIES INC
ATTN: C PETERSEN
ATTN: K D PYATT JR
ATTN: MARK GROETHE
ATTN: P COLEMAN
ATTN: S PEYTON

PACIFIC-SIERRA RESEARCH CORP
ATTN: H BRODE

SCIENCE APPLICATIONS INTL CORP
ATTN: C HSIAO
ATTN: G EGGUM
ATTN: H WILSON
ATTN: TECHNICAL REPORT SYSTEM

SCIENCE APPLICATIONS INTL CORP
ATTN: W LAYSON

SCIENCE APPLICATIONS INTL CORP
ATTN: G BINNINGER

SRI INTERNATIONAL
ATTN: A FLORENCE
ATTN: DR JIM GRAN
ATTN: J GIOVANOLA
ATTN: J SIMONS
ATTN: M SANAI
ATTN: P DE CARLI

SUNBURST RECOVERY INC
ATTN: C YOUNG

TECH REPS. INC
ATTN: F MCMULLAN

TITAN CORPORATION
ATTN: J ROCCO
ATTN: J THOMSEN
ATTN: S BABCOCK

TITAN CORPORATION (THE)
ATTN: R ENGLAND

WASHINGTON STATE UNIVERSITY
2 CY ATTN: PROF Y GUPTA

WEIDLINGER ASSOC, INC
ATTN: H LEVINE

WEIDLINGER ASSOCIATES, INC
ATTN: T DEEVY

WEIDLINGER ASSOCIATES, INC
ATTN: M BARON